THE VALSALVA MANOEUVRE AS A TEST OF THE CARDIAC RESPONSE TO SYMPATHETIC STIMULATION

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ABSTRACT

The object of the investigation was to find a simple test of cardiac function, using established methods, sufficiently sensitive to detect deterioration of function before the advent of clinical signs of heart failure. It was hoped, by comparing the heart rate response to stress with changes in the systolic time intervals, to be able thereafter to use the heart rate response alone.

The systolic time intervals have been noted to change with alterations in stroke volume, rate of flow and contractility. The most appropriate method of measuring these intervals, and the interpretation of these changes, was not altogether clear when the investigation was begun in July, 1969. Assumptions had therefore been made, based on the evidence available, and more recent work in the literature has proved these assumptions to be justified. These references, which refer to the use and significance of the pre-ejection period, ejection period and total systole, corrected for heart rate, have been included in the text.

A small pilot study was undertaken to determine whether change of posture, release of venous cuffs or leg raising could be employed as the stress but the results were inconclusive. A difference was then found between subjects in the time of the return of heart rate after the Valsalva manoeuvre and this was preceded by a change in a systolic time interval. Relevant factors were therefore reviewed and a plan of work designed.

It was concluded from the reviews that, if the heart reacted to changes in filling pressure by changes in stroke volume, then the ability to eject the blood rapidly in the presence of the resistance to flow induced by the manoeuvre would depend on the cardiac response to sympathetic stimulation. This would be reflected independently in the heart rate and systolic time intervals, corrected for heart rate.

After the manoeuvre the heart rate and corrected ejection period and total systole rose and then fell. But the time intervals altered to an unexpected degree and in a manner suggesting they were affected by the rise and fall of pressure and resistance. However, compared with control subjects, in patients with ischaemic heart disease corrected total systole and ejection periods increased more and - together with the heart rate - fell more slowly to their resting levels. In a larger series, the heart rate response alone (number of beats from onset of fall to control heart rate) differentiated control subjects from patients. The probable causes of these differences and the application of the findings are discussed.

ACKNOWLEDGEMENTS

Although the work has been my own, I am greatly indebted to Dr. R.H. Cutforth M.D., F.R.C.P., Director of the National Heart Foundation, for extending its facilities to me before any plan had been formed, for his helpful criticism of my approaches to the problem and suggestion to try the Valsalva manoeuvre. I received invaluable aid from my wife, Isobel Williamson S.R.N., S.R.F.N., who acted as my assistant during the recordings of the systolic time intervals and typed the drafts of the text. Mr. Lee, in charge of the Photographic Department, Clinical School, kindly reproduced the figures, and I am grateful to Mrs. Dann for her typing of the manuscript.

ABBREVIATIONS AND SHORTENED TERMS

Valsalva Manoeuvre

During strain	during the 10 seconds a pressure of 40 mmHg. was maintained.
After release	after the pressure was released.
End of strain	ditto.

Systolic Time Intervals

PEP	pre-ejection period.
LVET	left ventricular ejection time.
QS2	total electromechanical systole.
PEPc, LVETc, QS2c	the intervals corrected for heart rate.
S1-AO	the period from the first heart sound to the opening of the aortic valve.

Heart Rate

H.R.	heart rate.
Onset of fall	the beat after which the heart rate fell after release.
Increment	the increase in heart rate from control at the onset of fall.
R.B. or returning beat	the beat in which the heart rate returned to, or fell below, the resting level.
L.S.S.	lowest settled state of the heart rate after release.

Patients

I.H.D.	ischaemic heart disease.

THE VALSALVA MANOEUVRE

Perhaps originally used as a means of committing suicide (Kroeker and Wood, 1956, citing Dawson) raising the intrathoracic pressure by expiring against the closed nose and mouth was described by Valsalva as a method of expelling pus from the middle ear in 1704, and Weber reported some of the circulatory effects of forced expiration against his closed glottis in 1851 (Derbes and Kerr, 1955). Flack (1919 and 1921) asked flying personnel to blow a column of mercury to 40 mmHg. and to hold it for as long as possible, testing whether the subject was likely to suffer from oxygen want at high altitudes, the stability of the respiratory centre to diminished oxygen tension, and the degree of resolution.

Dawson and Hodges (1920), employing the string galvanometer, radial sphygmogram and auscultation described the beat-to-beat heart rate response and changes in blood pressure in man. Hamilton, Woodbury and Harper (1936) recorded changes in intrathoracic pressure, intra-arterial pressure, heart rate and pulse contour and divided the response into four phases. Phase 1. The blood pressure rises with the onset of strain and the pulse becomes slightly fuller. Intrathoracic pressure rises. The intrathoracic pressure minus the arterial pressure does not rise and soon begins to fall. Phase 2. Arterial pulsations become of the empty type with a narrow pulse pressure and the dicrotic pressure often as low as the diastolic. Later, there is a rise of arterial pressure over the intrathoracic pressure. Phase 3. On release of strain the blood pressure falls precipitously to the level of the intrathoracic pressure.

Phase 4. The pulse pressure widens, systolic and diastolic pressure increase, and the dicrotic notch is higher on the diastolic contour. These changes reach their maximum in 4 seconds. The heart rate slows markedly.

Hamilton, Woodbury and Harper (1944) showed that the blood pressure did not fall during strain or increase after release in a case of decompensated aortic regurgitation. The arterial pressure response was further examined by Sarnoff, Hardenbergh and Whittenberger, (1948) and the overshoot of systemic arterial pressure in Phase 4 was attributed to blood being put out of the left ventricle more forcefully against an intensely constricted peripheral arteriolar bed.

However, a flow overshoot could not be demonstrated using dye-dilution curves in normal subjects (McIntosh, Burnum, Hickman and Warren, 1954). There was a slight overshoot in left ventricular end-diastolic dimensions after release (Goldblatt, Harrison and Glick, 1963). Cohen, (1966) recorded aortic flow with an electromagnetic flowmeter in animal experiments and showed that a pressure overshoot may be accompanied by a flow per beat overshoot or a flow rate overshoot alone. Fox, Crowley Jr., Grace and Wood, (1966) using a constant-rate injection of dye, found in man that thoracic aortic flow decreased during strain, there was no change for the first 3 seconds after release and then the flow increased rapidly at first and then more gradually, to a maximum exceeding the control level. Greenfield Jr., Cox, Hermandez, Thomas and Schoonmaker, (1967) reported that a considerable amount of blood was required to distend the aorta after release and an overshoot in stroke volume and mean flow accompanied the pressure overshoot.

This supports the contention that the blood pressure overshoot depends, in part, on increase in left ventricular force - i.e. on stroke volume and rate of flow. The blood pressure response has been extensively investigated.

The Blood Pressure Response

The arterial pressure overshoot depends on the presence of reflex peripheral vascular constriction (Bondurant and Wallace, 1956) and proximal pulses in a limb are affected more than distal ones (Cooper, Skillman and Ciampa, 1967). In phase 2 the ascending aorta decreases in its cross-sectional area (Greenfield Jr. et al, 1967).

The rise in arterial pressure during the late straining appears to be due to vasoconstriction (Stone, Lyon and Teirstein, 1965; Ruskin, Harley and Greenfield Jr., 1968) and tachycardia is present in most normal subjects (Stone et al, 1965). It is possible that the increase in systemic arterial pressure and heart rate are caused, at least in part, by the tonically contracting thoracic, diaphragmatic, abdominal and pelvic muscles (Scott, Slawson and Taylor, 1969). The rise in pressure, and the associated tachycardia, was abolished by autonomic blockade (Greene and Bunnell, 1953). Patients with mitral stenosis maintained the systolic pressure in phase 2 despite autonomic blockade and the absence of systemic vasoconstriction (Greene and Bunnell, 1953). A pecularity of mitral stenosis is that the pulmonary wedge overshoot may occur alone or precede any brachial arterial overshoot by about 4 seconds (Gorlin, Knowles and Storey, 1957). There was no evidence of reflex pulmonary arterial vasoconstriction during the manoeuvre (Lee, Matthews and Sharpey-Schafer, 1954).

In the abnormal response the pulse pressure either does not fall or it increases during phase 2 (Hamilton et al, 1944; Sharpey-Schafer, 1955; Burroughs and Bruce, 1956) and there is no bradycardia. The abnormal response is associated with a raised resting right atrial pressure (Gorlin et al, 1957; Cudkowicz, 1968) or a raised resting pulmonary wedge pressure (Gorlin et al, 1957) or both (Gorlin et al, 1957) and the flow from the inferior vena cava may not be impeded (Stucki, Hatcher, Judson and Wilkins, 1955). There is gradation in the pulse pressure response in phase 2 and it may become narrow as in normal subjects, or intermediate, or not change as in congestive heart failure (Stucki et al, 1955). An intermediate response can be elicited, the response being normal in the head up position and abnormal in the horizontal position (Gorlin et al, 1957).

The blood pressure overshoot can be reduced or abolished by factors which influence flow and vasoconstriction - i.e. blood volume, the restriction to cardiac filling imposed by pericarditis, right and left heart failure, pulmonary disease, obstruction to flow, previous vasoconstriction, sympathectomy, drugs blocking reflex pathways, interference with the carotid sinus reflex, and vagal activity. The blood pressure overshoot is not necessarily a measure of the flow overshoot.

The pressure overshoot may be used as an index of circulating blood volume (Sarnoff et al, 1948) and was absent in some subjects after haemorrhage (Skillman, Olson, Lyons and Moore, 1967). It indicates the intactness of the sympathetic outflow (Sarnoff et al, 1948) and the effect of sympathectomy (Wilkins, Culbertson and Smithwick, 1948).

Circulating epinephrine reduces the response by limiting further vasoconstriction and excessive vagal activity limits the rise in pressure (Sarnoff et al, 1948). Body temperature affects the result (Sharpey-Schafer, 1955) as does interference by tetraethyl-ammonium chloride, bretylium tosylate, hexamethonium (Cohen 1966) probantheline bromide, guanethidine and alpha-methyl dopa (Cudkowicz, 1968).

The response may be abnormal in pericarditis (Elisberg, Singian and Miller, 1952; Price and Connor, 1953; Gorlin et al, 1957; Stone et al, 1965), mitral stenosis (Elisberg et al, 1952; Goldberg, Elisberg and Katz, 1952; Greene and Bunnell, 1953; Elisberg, Singian, Miller and Katz, 1953; McIntosh et al, 1954; Gorlin et al, 1957; Stone et al, 1965; Cudkowicz, 1968), aortic stenosis (Gorlin et al, 1957; Doyle and Neilson, 1957) and subaortic stenosis (Marcus, Westura and Summa, 1964) as well as in heart failure. The response has been used in the investigation of atrial septal defect (Aygen and Braunwald, 1962; Wennevold, 1967), and was found to be abnormal in large left-to-right shunts (Elison and Levin, 1968). Effective cardiac therapy can change the abnormal response (Judson, Hatcher and Wilkins, 1955; Gorlin et al, 1957).

In emphysema, or primary pulmonary disease, the mean pressure rise in phase 1 was smaller than in normal subjects and there was no cardiac slowing (Cudkowicz, 1968). In phase 2 there is a greater decline than normal in pulse pressure and systolic arterial pressure (Cosby, Herman, Freibrun and Mayo, 1958; Mills and Kattus, 1958; Stone et al, 1965; Cudkowicz, 1968). There was marked delay in the return

of the systolic pressure to the control level in phase 4 (Mills and Kattus, 1958) and there may be no bradycardia (Mills and Kattus, 1958; Cosby et al, 1958; Stone et al, 1965; Cudkowicz, 1968).

When other factors have been excluded, the abnormal response to the Valsalva manoeuvre has been attributed to the failure of the heart to respond to a decrease in filling pressure by a fall in stroke volume and, if the failure is more severe, the stroke volume may in fact increase (Sharpey-Schafer, 1955; Gorlin et al, 1957; Ruskin et al, 1968). Cardiac failure is characterised by the "square-wave" response in which there is (a) persistent elevation of systolic and diastolic pressure during strain with no decrease in pulse pressure and no change in heart rate and (b) absence of the overshoot of arterial pressure and also of the bradycardia after strain (Marx and Yu, 1967).

It seems likely that in the normal response there is an overshoot in the product of volume and rate of flow. In the presence of a varying degree of vasoconstriction there is a varying degree of blood pressure overshoot. The heart rate response depends on the blood pressure overshoot and is mediated through the carotid sinus reflex.

Carotid Sinus Reflex

Pressure alterations in the carotid sinus baroreceptor system produce reflex changes of heart rate and peripheral vascular resistance but, unlike ischaemia of the central nervous system, have little effect on ventricular performance (Downing and Gardner, 1968). The presso-receptors of the carotid sinus respond to both mean pressure and the rate of change of pressure. The sympathetic motor fibres fire most when the least information arrives from the pressoreceptors - i.e.

when carotid pressure is low. The fall in heart rate due to an increase in carotid pressure is greatest before the highest pressure is reached (Scher and Young, 1963).

The heart rate is exquisitively sensitive to very small pulsation pressures. Bradycardia occurs within one or two cycles and decrease in systemic arterial pressure in 6-10 cycles (Wilson, Clarke, Smith and Rushmer, 1961). The effector organ is faster on than off (Scher and Young, 1969) so that the vagal heart rate decrease may precede the relaxation of sympathetic vasoconstriction. Although slow overdamped responses lead to stability (Scher and Young, 1969) oscillation may occur if the "feedback" is strong enough (Guyton, 1967).

As the mean pressure increases, the effect of a superimposed pulse pressure on the baroreceptor response is reduced (Koushanpour and McGhee, 1969). If the blood pressure is elevated over a long period of time the baroreceptors adapt and their signal output gradually fades back to its normal level (Guyton, Coleman, Fourcade and Navar, 1969). Baroreflex sensitivity is reduced in chronic hypertension (Bristow, Honour, Pickering, Sleight and Smyth, 1969). In the Valsalva manoeuvre a blood pressure overshoot may be obtained in the presence of hypertension (Wilkins et al, 1948).

The baroreceptors serve to limit rise in blood pressure (Guyton et al, 1969) including the rise in blood pressure produced by hypothalamic stimulation (Gebber and Snyder, 1970). On the other hand, the baroreceptor-induced vagal bradycardia can be inhibited by hypothalamic stimulation (Gebber and Snyder, 1970).

It follows that:- (1) When a blood pressure overshoot occurs after the Valsalva manoeuvre, the heart rate may return to control before the blood pressure reaches its maximum but the maximum fall in heart rate may be related to the maximum fall in blood pressure. (2) As sudden ejection of the blood from the heart causes a greater pulse pressure than does more prolonged ejection (Guyton, 1967) it will cause a greater and more rapid fall of heart rate. (3) The fall in heart rate due to a blood pressure overshoot may be reduced in the presence of hypertension. (4) Hypothalamic activity may interrupt the bradycardia after the Valsalva manoeuvre. (5) Oscillation may occur.

The Heart Rate Response

The rapidity of the onset of the increase of arterial pressure in phase 1 was directly related to the speed of attaining the greatest rise of intrathoracic pressure. If the intrathoracic pressure was increased slowly, phase 1 was more prolonged (McIntosh et al, 1954).

The heart rate response to the manoeuvre was used by Elisberg (1963) as a test of function. In 51 healthy subjects the heart rate slowed with the onset of straining (phase 1) and this was less marked in patients with cardiac disease. All subjects were instructed to begin the manoeuvre suddenly.

During strain the heart rate increased over control by 26.1 beats per minute in the normal group and by 10.3 beats per minute in the cardiac group. The greater rise in heart rate was attributed to a greater fall in pulse pressure and increase in sympathetic stimulation.

Immediately after strain the heart rate increment in the normal group was 32.1 beats per minute and 13.8 beats per minute in the cardiac group.

In the cardiac group there was no bradycardia after release, and in fact, there was a mean increase in rate of 3.8 beats per minute.

In the normal group, at very slow control rates only a small change below the control value occurred in phase 4 and slowing in phase 4 was most marked at rapid control rates. The bradycardia occurred after the 5th beat. The most marked difference between the two groups occurred in phase 4, but it was found that several of the cardiac patients had a degree of change approximating the normal response in phases 2 and 3 and yet did not have a bradycardia.

In two patients from a third group the phase 4 bradycardia was delayed and occurred after the 12th and 17th beat respectively and this was thought to be due to encroachment of the heart's ability to respond to an increase in venous return by an increase in output (Elisberg et al, 1953).

The poststraining bradycardia is always associated with a systemic blood pressure overshoot but if the pressure overshoot is of mild degree, or delayed, then bradycardia does not occur (Elisberg et al, 1953).

The Range of the Response

When a normal or abnormal response to the Valsalva manoeuvre is judged by the presence or absence of a "square-wave" response, the clinical value of the test is limited since the response may be normal if only minor cardiac decompensation exists (Marx and Yu, 1967).

It is logical to assume that with increasing age and decreasing fitness the response will change progressively from normal to abnormal, but the evidence for such a range is not clear. However, Elisberg (1963) has pointed out that the response in phases 2 and 3 may be similar in normal subjects and in patients with heart disease while the response in phase 4 is markedly dissimilar. It would seem, therefore, that some of the cardiac patients decreased stroke volume during strain in the normal manner but failed to respond to the induced sympatho-adrenal stimulation.

While the accepted abnormal response to the manoeuvre depends on the ability of the heart to respond to changes in venous return, the accepted normal response may perhaps vary with the cardiac reaction to sympatho-adrenal stimulation and the rapidity of the clearance of the increased venous return to the left ventricle.

Bradycardia may be delayed when flow is altered. Thus the blood pressure overshoot may be delayed in mitral stenosis (Elisberg et al, 1953; Gorlin et al, 1957; Stone et al, 1965) and the bradycardia as well as being later may be of short duration (McIntosh et al, 1954). A delay in return to control values was noted in emphysema (Mills and Kattus, 1958) and the bradycardia was delayed in two subjects with heart disease (Elisberg, 1963). In a case of angina of effort described by Levine, McIntyre and Glovsky, (1966) it appears from Fig. 1, that the maximum systolic pressure occurred at the 12th beat after straining.

In normal subjects as the pulse rate falls after release the blood pressure is rising. Kay, Woods, Zinsser and Benjamin (1949)

recorded the aortic pulsations electrokymographically and it would seem (from Fig. 6) that the increase in the aortic pulsations reached its peak after the abrupt onset of cardiac slowing and approximately at the time of maximum bradycardia.

In three normal subjects, aged 22, 26 and 34, the control blood pressure was reached 5-8 beats after release (Goldberg et al, 1952). In eight normal subjects aged 36 to 47, the stroke volume and aortic pressure reached control values 6 to 9 beats after release but the maximum stroke volume occurred 6 to 15 beats after release (Greenfield Jr. et al, 1967). These time intervals are variable.

The duration of ejection tended to follow stroke volume in patients with congestive heart failure (Ruskin et al, 1968) and the rate-corrected systolic ejection time was shorter in subjects without the overshoot suggesting a diminished cardiac output (Stone et al, 1965). The duration of ejection increased in the 4 second period immediately following the manoeuvre in healthy subjects while the heart rate was still rapid (Kroeker and Wood, 1956).

It does seem possible, therefore, that there is a range in the accepted normal response, depending on cardiac function and which may be elicited by studying the response of the heart rate and systolic time intervals.

CARDIAC PERFORMANCE

The heart acts as a pump and, while its overall performance depends on that of its parts, it is also influenced by the preload, afterload, and degree of stimulation. Thus, although systolic ejection is the overall contractile response of the myocardium it is influenced not only by the effects of inotropic stimulation of the contractile elements but also by the effects of conduction, excitation, synchronous integration of the contractile process, and regional differences in the musculature (Gorlin and Sonnenblick 1968).

The clinical importance of assessing ventricular competence in terms of the mass ejected, acceleration, velocity and time was emphasized by Rushmer (1964). Measurements may be direct or indirect and may be altered by factors other than cardiac performance.

MOMENTUM AND OPPOSITION TO FLOW

Left ventricular ejection is characterised by the sudden imparting of momentum to the blood in the ventricle, peak momentum (mass times velocity) being normally attained early in systole (Spencer and Greiss, 1962; Noble, 1968). The driving force is the contracting myocardium (Rushmer, 1964). The contraction of the ventricular wall in a sequential manner maintains and increases the acceleration imparted to the blood (Taylor, Wade, Shishodia and Hider, 1968), and the ventricular wall continues to support a high pressure late in systole (Noble, 1968). The so-called oxygen wasting effect of norepinephrine on myocardial metabolism may be explained largely by an increased velocity of contraction (Sonnenblick, Ross Jr., Covell, Kaiser and Braunwald, 1965).

The total opposition to flow "impedance", is the sum of the opposition due to inertiance plus the opposition due to resistance. Inertiance may be expressed as a function of the density of the blood, and length and radius of the segment of the blood vessel. In the larger blood channels, inertiance is dominant (Spencer and Greiss, 1962). The mass will resist movement when a force is first applied because of its inertia, but once it is moving its momentum will tend to keep it moving even though the driving force is removed (McDonald, 1960) until it is stopped by resistance (Ambrosi and Starr, 1965) or decelerated by a negative pressure gradient (Noble, 1968).

Inertiance is increased where there is absence of the elastic storage capacity in the large vessels and the ventricle is compelled to accelerate large volumes of blood (Salisbury, Cross and Rieben, 1962). Ageing may increase the peripheral resistance. Thus, treadmill exercise revealed decade-by-decade increments of systolic, diastolic and mean blood pressure at all work loads (Hanson, Tabakin and Levy, 1966; Hanson, Tabakin and Levy, 1968). Hypertension, whether occasional or established, is associated with increased peripheral resistance (Julius and Conway, 1968) and the blood pressure may be high when the cardiac output has become reduced (Hamer, 1968).

Peripheral vasoconstriction causes a reduction in pulsatile flow and an increase in pulse pressure (McDonald, 1960) and pulseless flow may itself induce vascular resistance (Trinkle, Helton, Bryant and Wood, 1968; Papaevangelou, Moran and Callow, 1968). Conditions causing obstruction to flow have also to be considered (Rushmer, 1964).

Therefore, the momentum of the blood entering the aorta may not represent overall left ventricular performance if (a) there is resistance to forward flow, as in aortic stenosis, hypertrophic subaortic stenosis, co-arctation of the aorta; (b) change in inertiance, central or peripheral resistance; (c) when there is retrograde flow, as in aortic or mitral incompetence or septal defect and (d) when flow into the left ventricle is reduced or impeded, as in right heart failure, pulmonary hypertension, or mitral stenosis.

MOMENTUM AND CARDIAC PERFORMANCE

Simple Tachycardia

The left ventricle performs the same amount of stroke work over a wide range of heart rates without an increase in end-diastolic pressure in spite of the markedly shortened time available. The left ventricular mean rate of pressure rise and the maximal rate of pressure rise during isovolumic systole, and the mean rate of ejection all increased (Mitchell, Wallace and Skinner, 1963). The force of contraction is maintained with changes of heart rate, the intensity of the active state (peak df/dt) varying inversely with the duration of the active state (time to peak force), (Sonnenblick, Morrow and Williams, 1966). In the absence of augmented metabolic requirements, homeostatic mechanisms maintain cardiac output constant despite wide variations in heart rate (Braunwald, Sonnenblick, Ross Jr., Glick and Epstein, 1967).

Therefore, simple tachycardia, per se, does not alter overall ventricular performance.

Integration of Preload, Stimulation and Afterload

Braunwald states that, although simple tachycardia augments the velocity of myocardial contraction, the increase is greater in the presence of sympathetic stimulation at the same heart rate. The normal cardiac response (to exercise) involves the integrated effects on the myocardium of simple tachycardia, sympathetic stimulation, and the operation of the Frank-Starling mechanism. The quantity of norepinephrine released by sympathetic nerve endings in the heart is, under ordinary circumstances, dependent on the sympathetic nerve-impulse traffic. This mechanism is probably the most important one that regulates the position of the force-velocity and ventricular performance curves under physiological conditions. The adrenal medulla and other sympathetic ganglions outside the heart may, when properly stimulated by sympathetic nerve impulses, release catecholamines which are carried by the blood stream to the myocardium where they augment the contractile state (Braunwald, Ross Jr., and Sonnenblick, 1967). There may be a delay of 10 to 20 seconds from the onset of sympathetic stimulation until the full effect is reached (Guyton, 1967).

Stroke volume depends on the interaction between the factors determining the ventricular end-diastolic volume and the level of the contractile state and also on aortic impedance. Reduction of peripheral resistance and aortic impedance allows an increase in outflow (Braunwald et al, 1967), and may also increase the maximum rate of rise of left ventricular pressure (Hainsworth and Karim, 1969). Increasing the afterload, on the other hand, may reduce the ejected fraction (Hermann, Singh and Damman, 1969). Therefore, overall performance may appear to increase or decrease

if resistance to flow is reduced or augmented.

Heart Failure

Decline of myocardial contractility is associated with cardiac norepinephrine depletion, the ventricular performance curve cannot be elevated to normal levels by the sympathetic nervous system (Braunwald et al, 1967) and when the heart muscle fails, function is supported by exogenous norepinephrine (Pool and Braunwald, 1968; Spann, Mason and Zelis, 1969). When myocardial contractility declines, reduction in stroke volume is prevented by cardiac dilatation and an increase in the end-diastolic volume of the ventricle, the Frank-Starling mechanism being employed to maintain stroke volume at a normal level (Braunwald et al, 1967). The mechanical disadvantages of dilatation have been stressed by Burch, Ray and Cronwich (1952); Burch (1955a); and the large dilated left ventricle has essentially a constant volume-rate of output during systole (Burch, 1955b). But overt congestive failure is a late manifestation of the severely depressed heart and more subtle losses of ventricular performance precede any detectable abnormalities in haemodynamic performance (Spann et al, 1969).

Thus, when myocardial contractility declines, the overall performance during ejection may be normal for stroke volume but reduced for acceleration and momentum.

The Myocardium

Ventricular performance may be affected by the condition of the myocardium or its blood supply. Thus efficiency may be reduced by geometric factors such as ventricular size and shape and wall thickness or asynchrony of contraction (Pool and Braunwald, 1968). Ventricular

hypertrophy, in the absence of heart failure, is associated with a depression of the contractile state of each unit of myocardium although the absolute increase of total muscle maintains cardiac compensation (Pool and Braunwald, 1968). Myocardial disease however, is associated with dilatation and hypertrophy inappropriate for the load (Dodge and Baxley, 1968). While cardiac hypertrophy, developing after the heart muscle has fully developed, appears to represent a bulwark against failure it is possible that the capacity of the terminal vascular bed remains unchanged while the muscle hypertrophies (Bing, Bottcher and Cowan, 1968).

Total ventricular performance at any given level of end-diastolic volume is depressed when a portion of ventricular myocardium becomes nonfunctional or necrotic as occurs in myocardial infarction, even though the remaining myocardium functions normally (Braunwald et al, 1967). In coronary disease, reduction of maximum cardiac output may be related to a smaller mass of functioning contractile myocardial structures or a reduced coronary blood flow capacity (Benestad, 1968) and systolic ejection may be impaired on exercise, coronary disease subjects resembling a heart failure group despite absence of failure by the usual criteria (Messer, Levine, Wagman and Gorlin, 1963). The coronary arteriolar circulation may be adequate at rest but unable to dilate further (Gorlin, Brachfield, MacLeod and Bopp, 1959). Exercise may produce a precipitate rise in ventricular end-diastolic pressure prior to the onset of angina and electrocardiographic ischaemia with a corresponding increase in pulmonary artery pressure (Wiener, Dwyer and Cox, 1968).

In dogs, the left ventricular end-diastolic pressure was raised following myocardial damage (Taylor et al, 1968) and sudden coronary occlusion resulted in prompt reduction in peak flow rates and stroke volume (Rushmer, 1964). Compared with control subjects, patients with coronary artery disease had similar end-diastolic volumes at rest but higher end-diastolic pressures and the ejection fraction was significantly lower and correlated well with a reduction in the extent and rate of circumferential fibre shortening. It was concluded that patients with coronary artery disease had abnormalities of diastolic compliance and contractile performance (Bristow, Van Zee and Judkins, 1970). In the failing ventricle, larger changes in the left ventricular end-diastolic pressures are associated with smaller changes in the left ventricular stroke work (Ross and Braunwald, 1964).

Thus, failing hearts may have different defects and compensating mechanisms, but have in common failure of over-all performance.

Measurements of Cardiac Performance

Cardiac output, stroke volume, mean systolic ejection rate, ventricular end-diastolic pressure and volume, and the ejection fraction have been measured and used as indirect reflections of myocardial contractility, but all these determinations have limitations since they also can be altered by variations in ventricular loading and are not direct expressions of the inotropic state of heart muscle (Spann et al, 1969).

It is postulated that the rate of rise of intraventricular pressure (dp/dt) may be corrected for preload and afterload and thus express changes in contractility. Increase in contractility is

associated with increase of dp/dt at any developed isovolumetric pressure whereas the rate of rise of isovolumetric ventricular pressure related to the developed pressure was not altered by change of afterload (arterial diastolic pressure). When the arterial diastolic pressure alters as from a control state to an exercise state, the relationship between the rate of rise of isovolumetric pressure to the peak common developed isovolumetric pressure expresses change in contractility corrected for afterload. It is postulated, that to correct for simultaneous changes in preload, this ratio, (dp/dt)/CPIP, may be related to end-diastolic volume or circumference (Mason, 1969).

However, although after experimental damage to left ventricular papillary muscle max dp/dt decreased and the time to max dp/dt increased, after lateral myocardial damage there was no significant change in either max dp/dt or time to max dp/dt but after reaching the peak, the curve fell off rapidly (Taylor et al, 1968). So failure of contractility may be associated with failure to maintain max dp/dt. Also, although max dp/dt and the time of its attainment increased when the aortic diastolic pressure was raised between two beats, propranolol increased this tendency (Wildenthal, Mierzwiak and Mitchell, 1969).

It would seem therefore, that in some circumstances, the relationship between the rate of rise of intraventricular pressure and the developed pressure does not express change in contractility although momentum would change.

The velocity of contraction can also be determined directly by cineangiography or indirectly by measuring the velocity of blood flow in the aorta or main pulmonary artery. In order to assess volume the diameter of the vessel must be measured as by utilising biplane cine-aortography (Braunwald, Ross Jr., and Gault, 1969). The ratio of maximum aortic flow acceleration to stroke volume or peak flow has been proposed as an index of the left ventricular myocardial contractile state (Nutter and Hurst, 1968). But measurements of momentum may not always represent ventricular performance.

As it is difficult even with sophisticated methods to measure contractility, in intact man, whether in terms of individual contractile elements or the over-all contractile response, simpler methods may only be able to indicate change in the overall contractile response. External measurements indicating change in overall cardiac performance must indicate change inmomentum. If contractility increases with increase of preload, then momentum must increase. If the afterload is constant, then either the same stroke volume is ejected in less time or a greater stroke volume is ejected in the same time, or less time. If the afterload is known to have increased, and these changes in stroke volume and rate of flow occur, then contractility has increased further. The systolic time intervals have been used to indicate changes in cardiac performance.

SYSTOLIC TIME INTERVALS (Left Ventricle)

QS2

Total systole (QS2) extends from the onset of electrical systole to the closure of the aortic valve - i.e. from the onset of the QRS complex to the aortic component of the second heart sound.

PEP

The pre-ejection period (PEP) is the period from the onset of electrical systole to the opening of the aortic valve and comprises the electromechanical lag time and the isometric (isovolumic, isovolumetric) contraction time. The electromechanical lag is the time interval between the onset of electrical systole and the rise of intramural pressure. The isometric contraction time begins with the rise of intramural pressure, which is followed by a rise of cavitary pressure, and terminates with the opening of the aortic valve.

LVET

The left ventricular ejection time (LVET) is the time interval from the opening of the aortic valve to its closure.

PEP + LVET = QS2. Corrected for heart rate, PEPc + LVETc = QS2c.

Regression equations relating heart rate and the duration of ejection have been proposed by different authors. The ejection time index (ETI) is the left ventricular ejection time corrected for heart rate (LVETc) by the method of Weissler.

Electromechanical Lag

The electromechanical lag covers the period during which the action potential releases the activating calcium in the cell from the terminal store link into the contractile zone. Time to peak tension closely followed the duration of the action potential (Braveny and Sumbera, 1970). Although the resting potential and magnitude of the action potential are normal, contractile performance may be impaired due to a defect in excitation-contraction coupling (Rovetto and Lefer, 1970).

It seems therefore, that change in the electromechanical lag time would be associated with a similar directional change in the isometric contraction time and in the pre-ejection period.

Change from control in the pre-ejection period is a reliable index of the change from control of the isovolumic contraction time (Metzger, Chough and Kroetz, 1970).

Isometric Contraction

The isovolumetric contraction period depends on the rate of rise of left ventricular pressure and the pressure at which the aortic valve opens. The rate of rise of left ventricular pressure, assuming a constant inotropic state, will depend on the end-diastolic volume. A large end-diastolic volume and a low pressure at which the aortic valve opens will both tend to shorten the isovolumetric contraction period (Greenfield Jr., Harley, Thompson and Wallace, 1968), as will increase in contractility which also increases the rate of rise of pressure (Mason, 1969).

Ejection Period

The period of ejection may be divided into a rapid phase and a reduced phase (Wiggers, 1921). The phase of rapid ejection is characterised by the sudden imparting of momentum to the blood (Spencer and Greiss, 1962; Noble, 1968). In Wiggers studies (1921) the phase of reduced ejection was altered before the phase of rapid ejection by changes in venous return or peripheral resistance. The phase of rapid ejection may be affected by the state of the larger blood vessels (Spencer and Greiss, 1962; Salisbury et al, 1962).

As the ventricle may respond by changes in end-diastolic pressure and fibre length, or by change in myocardial contractility (Mitchell et al, 1963), the period of ejection may be affected by the venous return, cardiac contractility and change in opposition to flow.

As about half of the stroke volume is ejected during the first quarter of the period from the opening of the aortic valve to the onset of ventricular relaxation (Guyton, 1967), the ejection time is not a measure of the maximal ejection rate. Also, as there is no constant relationship between the time of the rapid and reduced phases, or the volume of blood ejected in them, the ejection time cannot be used as a reflection of the maximum ejection rate. Nevertheless, when corrected for heart rate, it has been shown to vary with stroke volume and rate of flow.

Stroke Volume

When the inotropic state was relatively constant, the duration of systole was relatively constant over a wide range of stroke volume in individual patients. The duration of ejection increased with increase

of stroke volume and the pre-ejection period decreased (Greenfield Jr. et al, 1968). In the isolated dog heart, when heart rate and mean aortic pressure were held constant, augmenting stroke volume shortened the duration of isovolumic contraction and lengthened the duration of ejection. When heart rate and stroke volume were held constant, elevating mean aortic pressure prolonged the duration of isovolumic contraction and decreased the duration of ejection. Total systole was little if at all altered by augmenting stroke volume or elevating mean aortic pressure (Wallace, Mitchell, Skinner and Sarnoff, 1963).

Thus, when the inotropic state is minimal or relatively constant, the duration of ejection varies directly with stroke volume and the duration of the pre-ejection period varies inversely with stroke volume within a framework of a relatively constant duration of total systole.

In man, stroke volume alters on passive change of posture when the inotropic state may be assumed to be relatively constant.

In normal individuals when the stroke volume increased on change of posture the ejection time increased linearly (Weissler, Peeler and Roehill, 1961). Tilting the body to the head-up position is associated with a diminished cardiac output and stroke volume and a rise in heart rate (Weissler, Roehill and Peeler, 1962) and with a decrease in the ejection time corrected for heart rate in normal subjects and in patients with heart failure (Weissler, Harris and White, 1963). In a more recent study, head-up tilt (when corrected for increase in heart rate) was accompanied by considerable shortening of left ventricular

ejection, prolongation of the pre-ejection period and minimal shortening of total systole in normal subjects (Stafford, Harris and Weissler, 1970).

Passive change of posture, therefore, employs the Frank-Starling mechanism.

Heart Failure

Patients with heart failure also had long pre-ejection periods, short left ventricular ejection times, and normal QS2 intervals (total systole). The prolongation of the pre-ejection period not only correlated well with a diminished stroke volume but also appeared to be independently augmented by a high level of mean and diastolic arterial pressures. (Above a mean arterial pressure of 110 mmHg. or above a diastolic arterial pressure of 90 mmHg.). The high level of arterial pressure could not be shown to influence the left ventricular ejection time (Weissler, Harris and Schoenfeld, 1968).

Patients with congestive heart failure studied in the supine position have systolic time intervals resembling those observed in normal subjects during head-up tilt. In both groups the shorter ejection time is associated with a reduction in stroke volume. In heart failure the left ventricular end-diastolic volumes are large and in the normal subjects they are small (Stafford et al, 1970).

Ejection Fraction

Therefore, in patients with congestive heart failure in the supine position and in normal subjects during head-up tilt, the systolic time intervals correlated with the effective stroke volume and not with the ejection fraction.

In patients with valvular regurgitation the systolic time intervals correlated better with the ejection fraction than with the effective stroke volume (Garrard, Weissler and Dodge, 1970).

Rate of Flow

In the isolated dog heart, inotropic agents (digitalis and norepinephrine) shortened all phases of systole (Wallace et al, 1963). In normal subjects deslanoside diminished each phase of systole (Weissler, Kamen, Bornstein, Schoenfeld and Cohen, 1965). Also, following deslanoside administration, the ejection time (corrected for heart rate) fell although the stroke volume increased. Since the increase in mean arterial pressure was slight it was not responsible for the diminution in the duration of ejection and the left ventricular stroke volume was therefore delivered at an increased rate of flow (Weissler, Gamel, Grode, Cohen and Schoenfeld, 1964).

In the dog, aortic pressure was increased by increasing aortic resistance while stroke volume and heart rate were held constant. When the mean aortic pressure was increased from 114 ± 8 to 139 ± 8 mmHg., the left ventricular end-diastolic pressure increased by 3.5cm.H20 and the mean rate of ejection decreased by 7 m./sec. (Mitchell, Wallace and Skinner, 1966).

In man, with heart rate and stroke volume index held constant, the infusion of methoxamine produced an average increase in mean arterial pressure of 27 mmHg. and in mean systolic pressure of 31 mmHg. Both the left ventricular ejection time and the pre-ejection period increased. In one subject an elevation of mean systolic pressure of 75 mmHg.

prolonged left ventricular ejection time 55 msec. (Shaver, Kroetz, Leonard and Paley, 1968).

The ejection time therefore, varies directly with stroke volume and inversely with rate of flow when corrected for heart rate. The pre-ejection period varies inversely with end-diastolic volume and directly with diastolic arterial pressure.

Significance of Systolic Time Intervals

If the systolic time intervals are to indicate loss of ventricular performance before the advent of haemodynamic failure then they must be capable of showing loss of momentum. The pre-ejection period (PEP), the left ventricular ejection time (LVET) and total electromechanical systole (QS2) have been used in different ways.

The PEP, LVET and QS2 intervals have been shown to alter predictably with heart rate and the normal range for these intervals has been established for subjects in the resting state. By means of regression equations, the normal range of these intervals can be obtained for any given level of heart rate and sex and it can then be determined whether the measured values from a patient are within or without the normal range (Weissler et al, 1968).

Regression equations relating heart rate and duration of ejection may be calculated for individual patients (Harley, Starmer and Greenfield Jr., 1969) or from pooled data (Weissler et al, 1963; Spodick and Kumar, 1968c). The regression line used by Spodick and Kumar (1968c) relating ejection time to heart rate agreed extremely well with that of Weissler et al, (1961) over the range of heart rates

studied (Spodick and Kumar, 1968c). Although regression equations obtained from pooled data may not be as accurate as regression equations calculated for individual patients (Harley et al, 1969) both Harley et al, (1969) and Weissler et al, (1963) found that stroke volume is an important determinant of the duration of ejection. Thus, in the resting state, the duration of ejection can be predicted from the heart rate.

The observed value is compared with the predicted value. The observed value of the LVET was abnormally low in patients with heart disease (Spodick, Dorr and Calabrese, 1969). Compared with the predicted value, the observed value for the PEP was prolonged, and for LVET reduced, in heart failure (Weissler et al, 1968) and in acute myocardial infarction (Wayne, 1968), reflecting reduction in stroke volume. Diamant and Killip, (1970) found that the QS2 interval was shortened in acute myocardial infarction, particularly when the infarction was transmural, the decrease in the LVET being greater than the increase in PEP and it was concluded that the stroke volume was reduced due to loss of myocardial contractility. During and after the Valsalva manoeuvre the observed LVET departed widely from the LVET predicted from heart rate and this was attributed to the close dependence of the LVET on stroke volume (Flessas, Kumar and Spodick, 1970). In hyperthyroidism, the isovolumic contraction and ejection times were both reduced, whereas in hypothyroidism they were both increased, thus illustrating the effect on these time intervals of myocardial contractility (Amidi, Leon and De Groot, 1968).

Alternatively, by means of the regression equations, the measured time intervals can be corrected for heart rate. The corrected time intervals can then be shown to vary with factors other than heart rate in individual subjects and can also be compared with the normal range. This method is suitable for non-basal states and is used in this study.

Or, the PEP and LVET intervals may be expressed as a ratio (PEP/LVET) uncorrected for heart rate. In patients with heart disease, the correlation of the prolongation of the PEP with reduction in cardiac output and stroke volume was similar to the correlation of the PEP/LVET ratio, although the correlation of the abbreviation in the LVET was not as close. In the patients studied, total electromechanical systole remained unchanged (Weissler, Harris and Schoenfeld, 1969). This method was proposed as a bedside technique and it would seem that in non-basal states when the QS2 interval may change, it would be advisable to compare one interval with another rather than as a ratio. Also, while the PEP interval shortens with both increase in stroke volume and inotropic agents, the LVET interval increases with increase of stroke volume but decreases with increased rate of flow.

The systolic time intervals, corrected for heart rate, may be termed QS2c, PEPc and ETI (Ejection time index) or LVETc. The ETI has been evaluated.

Ejection Time Index

The left ventricular ejection time (LVET) can be corrected for heart rate by means of the ejection time index (ETI), where, in males, ETI = LVET + 0.0017HR (Weissler et al, 1968). The ejection

time index represents alterations in the duration of left ventricular ejection, in seconds, induced by variables other than heart rate (Weissler et al, 1964). The ETI is reproducible and bears a constant relation to heart rate in the range 50 to 150 beats per minute in both children and adults (Weissler et al, 1963).

The ETI may be used in individuals and in group studies on factors influencing the duration of ventricular ejection, but should be limited to individuals without aortic valvular disease (Weissler et al, 1963) where prolongation of ejection time relative to stroke volume is a more predictable finding (Weissler et al, 1961). The difference between consecutive readings of an ejection time index in the same individual represents the absolute change in ejection time between the two observed values (Weissler, Snyder, Schoenfeld and Cohen, 1966).

At any level of heart rate, a change in the duration of left ventricular ejection, unaccompanied by alteration in stroke volume or peripheral resistance, denotes a primary alteration in the state of myocardial contractility (Weissler et al, 1966).

When stroke volume, peripheral resistance and contractility all change then the ETI will vary directly with changes in stroke volume due to changes in end-diastolic volume and inversely with increase in rate of flow. Changes in peripheral resistance will affect the ETI according to whether volume or rate of flow are changed. Increase in contractility may produce changes in stroke volume and in rate of flow. LVETc = ETI derived by the method of Weissler.

PEPc, LVETc, QS2c

It is apparent that there are considerable difficulties in assessing changes in these time intervals without recourse to direct measurements of volume, pressure and flow but the following interpretation can be suggested.

In the absence of significant changes in aortic impedance and peripheral resistance, relative constancy of the QS2c interval is associated with relative constancy of the inotropic state and changes in the PEPc and LVETc reflect changes in stroke volume if regurgitant flow is excluded. Under these conditions change in stroke volume is affected by the Frank-Starling mechanism.

Change in the PEPc and LVETc on passive change of posture demonstrate whether the ventricle can respond to changes in end-diastolic volume by change in stroke volume. The manoeuvre invokes little change in contractility or rate of flow.

An increased PEPc, probably resulting from a slow rate of rise of isovolumic pressure, may either be due to haemodynamic heart failure, where the response to stretch of the ventricular wall is already impaired by dilatation, or due to lack of stretch of the ventricular wall when the end-diastolic volume is small. In either instance the LVETc is correspondingly reduced. When patients with heart failure and normal subjects are placed in the head-up tilt position the PEPc is relatively long and the LVETc relatively short. But when both groups are then placed in the supine position, the decrease in the PEPc and the increase in the LVETc are greater in the normal subjects.

Reduction of the QS2c may be due to (a) increased inotropism, when both the PEPc and LVETc are reduced, and (b) acute myocardial infarction, the decrease in the LVET being greater than the increase in the PEP.

A high level of arterial pressure will prolong the PEPc, and a reduction of aortic pressure will shorten the PEPc, but the effect on the LVETc will depend on the inverse relationship between volume and rate of flow.

Thus (1) When the heart responds to increase in end-diastolic volume by increase in stroke volume, but without change in contractility, PEPc is reduced, LVETc increased and QS2c remains relatively constant.

(2) If the end-diastolic volume and contractility both increase then PEPc is reduced, the LVETc is unlikely to increase and will decrease if the increase in stroke volume is delivered at a sufficiently increased rate of flow.

(3) Change in arterial pressure, by altering both the pressure at which the aortic valve opens and the opposition to flow, will affect these time intervals.

Valsalva Manoeuvre

In the normal Valsalva Manoeuvre, increase in venous return on release acts as preload and the induced increase in arterial vasoconstriction during strain acts as afterload. Stress reveals diminution of cardiac reserve (Ross and Braunwald, 1964; Hood, McCarthy and Lown, 1969) and latent contractility (Sonnenblick and Downing, 1963). As the level of the mean aortic pressure is dependent only upon cardiac output and peripheral resistance (Berne and Levy, 1967),

the aortic pressure will rise when output exceeds outflow and this will depend on contractility as well as on the degree of peripheral resistance. Independent changes in peripheral resistance may be caused by emotion, cold, digestion and other factors.

It was realised that lack of correction for preload and afterload would affect the interpretation of the results. Nevertheless, it was anticipated that a difference in the rate of increase of output over outflow would be reflected in the systolic time intervals and in the heart rate and indicate whether the heart was depending largely on the Frank-Starling mechanism or whether this mechanism was integrated with a response to sympathetic stimulation - i.e. whether or not the cardiac norepinephrine stores were depleted.

If this is so, the Valsalva Manoeuvre could be interpolated between change of posture and exercise as a test of cardiac performance.

THE EXTERNAL CAROTID PULSE

Beat-to-beat changes in stroke volume have been calculated from the aortic pulse contour (Warner, Swan, Connolly, Tompkins, and Wood, 1953; Warner, 1966; Kouchoukos, Sheppard, McDonald and Kirklin, 1968; Graves, Stauffer, Klein and Underwood, 1968); from the difference between the aortic mean and diastolic blood pressures (Herd, Leclair and Simon, 1966); and from the time derivative of aortic pressure (Jones, Hefner, Bancroft and Klip, 1959; Jones and Reeves, 1968).

Warner et al, (1953) proposed that changes in stroke volume might be derived from a single peripheral intra-arterial pulse, but there is no method at present of calibrating an external pulse tracing with beat-to-beat systolic and diastolic pressures taken by external means (Howard, 1965; London and London, 1966; Sokolow, Werdegar and Kain, 1966; Weil, Shubin and Rand, 1966; Lategola, Harrison and Barnard, 1966; Kemmerer, Stegall and Evans, 1967).

Intra-arterial measurements in the brachial artery have been used to reflect the character of left ventricular ejection (Mason, Braunwald, Ross Jr. and Morrow, 1964; Gould and Shariff, 1969) and the internal carotid pulse may correspond with the aortic (Freis, Heath, Luchsinger and Snell, 1966). In the external carotid pulse derivative a greatly diminished positive deflection occurred at the onset of ejection and the maximum ejection velocity was attained abnormally late in systole in cardiac myopathy (Ambrosi and Starr, 1965).

The wall of the carotid artery shows a considerable increase in stiffness compared with the wall of the ascending aorta (Greenfield Jr., Tindall, Dillon and Mahaley, 1964). Rise of pressure depends on the stiffness of the arterial wall as well as on how much, and how rapidly, it is stretched (Marx and Yu, 1967). When there is a large stroke volume the initial rise of the external carotid pulse may be augmented compared with the aortic pulse (Robinson, 1963b). The external pressure of the pick-up may cause distortion (Dontas, 1960; Chlebus, 1962) accentuating the initial rise (Freis et al, 1966).

The external carotid pulse wave, although dependent on the acceleration and flow of the aortic blood column (Freis et al, 1966) is altered by aortic wall rigidity (Reeves, Hefner, Jones and Sparks, 1957), change in peripheral run-off (Freis et al, 1966) and occlusive disease of the carotid artery, ageing, and hypertension (Duchosal, Ferrero, Leupin and Urdanetta, 1956; Daoud, Reppert Jr., and Butterworth, 1959; Robinson, 1963a; Freis et al, 1966). The interval from the foot to the summit of the carotid pulse increases with age and then may become stable (Dontas, Keys and Anthopoulos, 1970). In the lower extremities the pulse wave form has been used to assess arterial disease (Kettner, Ferrero and Duchosal, 1955; Edwards and Ottinger, 1958; Lalossis, Dontas, Balas and Christeas, 1966; Cooper et al, 1967; Carter, 1968).

The external carotid pulse may show two summits and the pulse wave fall between them (Robinson, 1963a) perhaps due to movement of the artery (Freis et al, 1966). In normal subjects the first

summit is of greater magnitude than the second (Freis et al, 1966). With increasing age the second summit rises. In the elderly and in hypertension the second summit may be higher than the first (Freis et al, 1966), the first being absent or reduced (Robinson, 1963a). There may be a second summit in subaortic stenosis and in idiopathic left ventricular hypertrophy (Benchimol, Legler and Dimond, 1963). In the hyperkinetic heart syndrome the brachial arterial pressure pulse was of bisferiens quality (Gorlin, 1962) and it is possible that the syndrome is related to subaortic stenosis (Krasnow, Rolett, Hood, Yurchak and Gorlin, 1963). Pulsus bisferiens has been redefined as a palpable double pulse (Barner, Kaiser, Willman and Hanlon, 1968).

The conventional carotid pulse was similar in subjects of the same age with and without previous coronary occlusion (Dontas and Simonson, 1961). Irregularities, emphasized in the first derivative, may be interpreted as being due to inco-ordination of left ventricular contraction, the blood not being accelerated smoothly (Starr and Ogawa, 1963; Starr, 1967).

In conclusion, analysis of the external carotid pulse wave in the basal state may reveal changes due to age, hypertension and local disease of the artery. Under varying conditions of momentum and opposition to flow, both summits are affected by the condition of the carotid wall. Conditions governing acceleration of the aortic blood column alter the first summit and conditions determining the rate of run-through in the carotid segment (aortic flow and run-off) mainly affect the second summit. The pulse wave may further be changed by movement of the artery and the pick-up.

TECHNIQUE

Carotid Pulse

The carotid pulse has been recorded by means of an air-filled cuff round the neck (Duchosal et al, 1956; Daoud et al, 1959; Robinson, 1963a), a funnel-type of cup applicator (Benchimol et al, 1963; Weissler et al, 1968), a water-filled capacitance transducer applied to the skin (Freis et al, 1966), a short iron rod attached to a capacitance transducer (Ambrosi and Starr, 1965), and a resonance receiver (Chlebus, 1962). A photo-electric pulse pick-up has been employed to record pulsations from the praecordium (Berry, 1965).

The cuff system seemed the simplest for the purpose of the Valsalva manoeuvre and a paedriatic blood-pressure cuff, at a pressure of 20 mmHg. was found suitable. The same pressure was used by Duchosal et al, (1956) and Daoud et al, (1959) and an equivalent pressure by Freis et al, (1966).

Systolic Time Intervals

Ejection

The left ventricular ejection time has been determined from the interval between the beginning of the upstroke of the external carotid pulse to the trough of the incisura. There was close agreement in the ejection times as determined from these external pulse tracings and from the direct aortic pressure pulse (Benchimol, Dimond and Shen, 1960; Weissler et al, 1961). The left ventricular ejection time increases significantly with age and increase of systolic blood pressure (Willems, Roelandt, De Geest, Kesteloot and Joossens, 1970).

Isometric Contraction

The period of isometric contraction has been obtained by subtracting the left ventricular ejection time from the duration of mechanical systole measured from the interval between the heart sounds (Frank and Kinlaw, 1962; Harris, Weissler, Manske, Danford, White and Hamilton, 1964; Benchimol and Ellis, 1967).

However, the first heart sound may be delayed in mitral stenosis (Wells, 1954; Weissler, Leonard and Warren, 1958), in hypertension (Weissler et al, 1958), and due to a reduced rate of left ventricular pressure rise in heart failure (Weissler et al, 1968). Prolongation of the interval between the onset of the QRS complex and the first heart sound may be due to electrical conduction delay, impairment of contractility or elevation of left atrial pressure (Nimura, Matsua and Mochizuki, 1968). In order to avoid using the first heart sound Harrison, Dixon, Russell, Bidwai and Coleman, (1964) assumed a value of 0.038 sec. for the electromechanical lag. But this introduces a relatively large error (Agress, Wegner, Bleifer, Estrin, Schroyer and Labins, 1964a).

The first detectable mechanical event of the cycle in dogs is the onset of the initial systolic wave of the apex cardiogram (Inoue, Young, Grierson, Smulyan and Eich, 1970). In man the onset of the upstroke of the apex cardiogram is closely related to the initial rise of ventricular wall tension, while the first rapid component of the first heart sound is a relatively late phenomenon during isometric contraction (Spodick and Kumar, 1968a; Spodick and Kumar, 1968b).

Praecordial pulsations have been used to estimate systolic time intervals and are briefly reviewed.

The impulse cardiogram is a graphic representation of the pulsations felt by the hand and showed a pre-ejection wave and an ejection wave, the ejection wave starting just before the upstroke of the carotid pulse; but in some subjects with left ventricular hypertrophy the division between the pre-ejection and ejection waves was abolished (Beilin and Mounsey, 1962).

The apex cardiogram records the movements of a small area of chest wall in relation to the surrounding area (Beilin and Mounsey, 1962) and is a composite tracing produced in large measure by movements of the heart, changes in the volume of the left ventricle and probably by velocity of blood flow (Coulshed and Epstein, 1963; Tafur, Chem and Levine, 1964).

The "a" wave reflects left ventricular filling due to left atrial contraction and after its inscription the tracing rises rapidly (representing an increase in intramural tension and the onset of isometric contraction) to reach a sharp peak called the "E" point coinciding with the beginning of the upstroke of the aortic pressure curve (Benchimol and Dimond, 1963).

The summit of the tracing may be rounded or notched and the "E" point is then taken from the end of the straight upstroke (which precedes the carotid upstroke by as much as the carotid lag); the summit may then be above the "E" point in the normal apex cardiogram (Lohr, Van Vollenhoven and Van Rotterdam, 1963). The configuration of the systolic complex is subject to great variations depending on the

spatial relationships of the pick-up to the apex (Rios and Massumi, 1965). Also, the apical impulse is not always produced by the same area of the left ventricle (Deliyannis, Gillam, Mounsey and Steiner, 1964).

Thus, although the onset of isometric contraction is sharply inscribed, the end of this period may not be so clear on the apex cardiogram. This point is emphasized because Tafur et al, (1964) found that the maximal systolic peak of the apex cardiogram coincided with the onset of the upstroke of the carotid pulse which they took in support of the view that there is virtually no time lag between the onset of left ventricular ejection and the onset of the upstroke of the indirect carotid tracing.

The vibrocardiogram records praecordial vibrations by means of a capacitance microphone from an area between the 4th to the 5th left intercostal spaces near the sternum. The gross, or total, wave form has been shown to be made of curves closely resembling the apex cardiogram, accelerogram and phonocardiogram and may be examined using the conventional ballistocardiographic system or in the form of a spectrosonogram, where the frequency range 3-50 c.p.s. is subjected to frequency analysis, (Agress and Fields, 1959; Agress and Fields, 1961; Nakakura, Agress and Wegner, 1965; Agress et al, 1964a; Agress, Wegner, Bleifer, Lindsay, Van Houten, Schroyer and Estrin, 1964b; Agress and Nakakura, 1964).

According to Lohr et al, (1963), however, there are difficulties in the interpretation of the vibrocardiogram.

It seems that the isometric contraction time is most

accurately recorded, using external means, by the method of Spodick and Kumar, (1968b) who use the apex cardiogram to record its onset and the carotid pulse its termination. The delay in pulse transmission from the aorta is estimated by the interval from the aortic second sound to the carotid incisura.

This method was tried in the Valsalva manoeuvre but has too many disadvantages particularly for one observer. The apex disappears during strain and shifts on release as the heart fills with blood. The apex impulse is often weak in the class of patients studied. The observer has to watch a pressure dial, the screened apex tracing, and the tracings on the recording instrument. He also has to hold a funnel at the apex, manipulate the time marker and control the base lines on the recorder. The method was found impracticable to use routinely.

The pre-ejection period was used instead and it has since been stated that change from control in the pre-ejection period is a reliable index of the change from control of the isovolumic contraction time (Metzger et al, 1970).

The ejection time and the QS2 interval have been corrected for heart rate (Weissler et al, 1968). The pre-ejection period, corrected for heart rate, was obtained by subtracting the ejection time from the QS2 interval when both had been corrected for heart rate although this was not suggested by Weissler and associates. These time intervals, corrected for heart rate, are called PEPc, LVETc and QS2c.

Valsalva Manoeuvre

The manoeuvre may possibly give rise to syncope, angina, infarction and arrthymias.

The almost habitual practice of the manoeuvre has resulted in ptosis and proptosis, presumably from rupture of an ethmoidal air cell with extension of the air into the orbital cavity. The condition rapidly resolved (Chadduck and Ames, 1969).

Hyperventilation should be avoided before the manoeuvre to reduce the risk of syncope (Klein, Saltzman and Heyman, 1964). All the subjects in this study were working and the test was not performed if the preliminary test evoked frequent premature beats.

When a subject's position is changed from recumbency to head-up tilt and back to recumbency there is a delay of at least 11 to 25 minutes before the cardiac output reaches the level recorded before tilting (Tuckman and Shillingford, 1966). In a prior trial repetition of the manoeuvre altered the response. Therefore, after a subject was instructed in the Valsalva manoeuvre, a period of 25-30 minutes was allowed before the actual test.

The subject should take a deep breath (Burroughs and Bruce, 1956, citing Rushmer). Provided the glottis remains open, the intra-oral pressure corresponds to the intra-pleural pressure (Elisberg, Goldberg and Snider, 1951). Errors may be introduced by opposing the tongue and soft palate (Sharpey-Schafer, 1955) or using cheek pressure (Mills, 1950). Maintaining a pressure of 40 mmHg. for 10 seconds is adequate (Stone et al, 1965).

With one exception, no patient was tested who was taking digitalis as this augments the contractile state (Sonnenblick, Williams, Glick, Mason and Braunwald, 1966; Daggett and Weisfeldt, 1965; Murphy, Schreiner, Bleakley and Yu, 1964; Mason and Braunwald, 1963). The exception was the only subject receiving propranalol.

Carotid sinus sensitivity to massage and compression, especially on the right side, is increased in arteriosclerosis. Patients who are also using digitalis are apt to respond with asystole and atrioventricular block. Marked sensitivity was found in patients with stenosis of one or both of the internal carotid arteries (Brodie and Dow, 1968). Cuff pressure was not raised above 20 mmHg. and no adverse reactions were observed.

METHOD

Selection of Subjects

81 Male subjects were selected. 52 acted as control subjects and 29 had ischaemic heart disease.

The control subjects were selected from volunteers in whom there was no evidence of ischaemic heart disease or valvular heart disease as judged by the history, clinical examination and the electrocardiogram.

The patients with ischaemic heart disease (IHD) were selected from the hospital records by permission of the physician concerned. All these subjects had been admitted to hospital with chest pain. In 28, the electrocardiogram had shown evidence of myocardial infarction. The infarct was subendocardial in 1, septal in 1, anteroseptal in 7, lateral wall in 3, inferolateral wall in 5, inferior wall in 9 and posterior wall in 2. The serum enzymes were raised in 19 cases of infarction and in the one case in which there was electrocardiographic evidence of ischaemia of the inferior wall. (S.G.O.T. 34-202 Frankel units; LDH 500-2,480 BB units/ml.). In 3 cases the S.G.O.T. was raised and in one of these the LDH was suggestive of infarction. The serum enzymes were suggestive of infarction in 5 and not obtained in 1.

Groups

The 52 control subjects were divided into groups 1-4, according to age. The 29 patients with IHD formed group 5. Each subject in a group was given a number. The subjects in groups 2,3, 4 and 5 were numbered according to age. The subjects in group 1

were numbered mainly according to age but 6 athletes were given the numbers 1 - 6. (Table 1).

Clinical Findings

Age, blood pressure, occupation and significant findings are arranged according to the group and the number in the group. (Table 1). Cardiac enlargement was sought on clinical grounds in the control subjects. In the patients with IHD it was sought clinically and also in the hospital records from the clinical and radiological reports. No case had peripheral oedema, parasternal crepitations or orthopnoea. Basal rales were present in both control and IHD subjects.

A pansystolic apical murmur was heard in 4 patients. There was no history of rheumatic valvular disease and the murmur was soft and changed on posture. In 2 of these patients the heart sounds were recorded before and after the Valsalva manoeuvre but the murmur did not appear on the record in the position adopted for the test, either at rest or after release. The murmur was not regarded as evidence of significant retrograde flow. In one patient with IHD, an alcoholic, the liver was grossly enlarged and the jugular venous pressure raised but there was no evidence of valvular heart disease.

The control group included 6 young competitive athletes at school or university and male nurses of similar age. The other control subjects were male nurses or technicians.

Patients with ischaemic heart disease were chosen whose

activity at work was not limited by angina of effort but 7 patients were accepted in whom chest tightness or pain developed on more severe exertion such as hurrying or walking uphill. Most had sedentary occupations, some having changed employment since the infarction, but included two warders on outside duties, two lorry drivers who also had to load the vehicle, an able seaman, a marine pilot and a nurse.

Valsalva Manoeuvre

A Valsalva-like manoeuvre was performed 25-30 minutes after the physical examination and a short trial. Hyperventilation was avoided before the test and the room temperature was maintained around 70 deg. F. The subject lay on his back in a slight (approximately $3\frac{1}{2}$ degree) head-up position with the neck somewhat extended and supported by pillows. After a control period of quiet breathing he took a deep, but not slow, breath and blew into a tube attached to an anaeroid manometer, maintaining a pressure of 40 mmHg. for 10 seconds, counted by a tape recording. Two rectangular openings had been cut into the intra-oral portion of the tube. The manometer was held by an assistant, in a position where it could also be seen by the subject and the operator, who checked that the subject did, in fact, strain. The subject released the pressure abruptly, inhaled and then breathed quietly.

As all the subjects were asked to come in for a test, a test was always done - although in a modified form if the subject was in clinical heart failure, or had frequent premature beats in the resting record, or could not maintain a pressure of 40 mmHg. for the

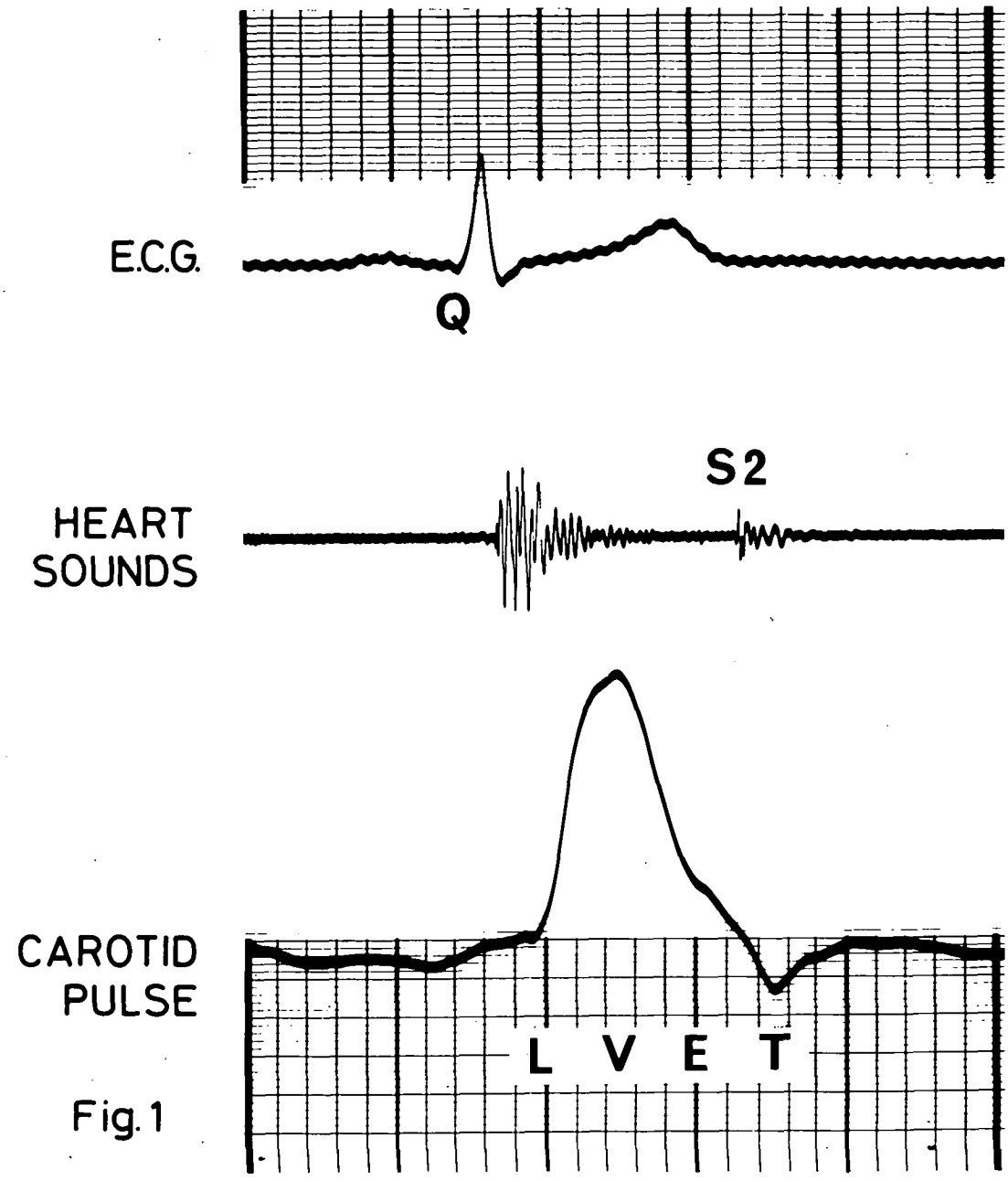


Fig. 1

Measurement of the QS2 and LVET.

ten seconds. Some patients with ischaemic heart disease, who were fully employed and performed the test satisfactorily, gave abnormal responses - in that there was little change in the heart rate on straining or after release - and were not included in the study.

Systolic Time Intervals

The electrocardiogram, heart sounds and carotid pulse were recorded simultaneously on a model 564 Sanborn Poly Beam Recorder at a paper speed of 100 m/sec. The electrocardiogram was selected from the standard limb leads which showed most clearly the onset of the QRS complex. With one exception, all subjects had a QRS interval of 0.10 sec. or less. A crystal microphone was placed at the cardiac apex and the heart sounds recorded at 100 c/sec. A paediatric blood pressure cuff, inflated to a pressure of 20 mmHg. was used to transmit the carotid pulsation to a Statham strain gauge. At the end of the manoeuvre the pressure in the cuff had not fallen more than 3 mmHg.

The left ventricular ejection time (LVET) was measured from the onset of the carotid pulse to the incisura (Fig. 1.) and was corrected for heart rate (LVETc) by means of the ejection time index (ETI) where, in males, ETI = LVET + 0.0017HR (Weissler et al, 1968; Weissler et al, 1963; Weissler et al 1964). Total electromechanical systole (QS2) was measured from the onset of the QRS complex to the first high frequency vibrations of the aortic component of the second heart sound and was corrected for heart rate in accordance with the regression equation given by Weissler et al (1968) and termed the QS2c. QS2c = QS2 + 0.0021HR in males. The pre-ejection period corrected for heart rate was obtained by subtracting the ETI (LVETc) from the QS2c

interval and termed the PEPc interval. The left ventricular ejection time was subtracted from the duration of mechanical systole measured from the interval between the heart sounds (Frank and Kinlaw, 1962; Harris and Weissler et al, 1964; Benchimol and Ellis 1967) and termed the S1-AO interval (first heart sound to aortic opening) to avoid using the term isometric contraction time.

The film was developed, marked and measured. A line was drawn through each point of measurement to intersect the time markers at the top and bottom of the film, care being taken to ensure that the line intersected the time markers at the same point of time. The measured time intervals, and the time intervals corrected for heart rate, were recorded on prepared sheets. Each tracing took 6 hours to mark, and $5\frac{1}{2}$ hours to measure and record, including examination of the electrocardiogram and carotid pulse wave form.

52 records were examined from 39 subjects. In 20 instances only the electrocardiogram could be measured owing to movements of the chest wall and neck and swallowing altering the record, or due to lack of definition.

The systolic time intervals and heart rate were measured in 21 control subjects and in 10 patients with IHD. In one patient the record was repeated.

The ejection time was measured during strain. The ejection time and total systole were measured for 10 beats in the control period and, when clearly defined, for at least 10 beats after release on a beat-to-beat basis.

The pre-ejection and ejection periods were measured in 15

control subjects and in 6 patients with IHD. The ejection period was measured in other 4 control subjects and in 2 patients with IHD. In all of these cases the heart rate increased during strain and after release and there was no arrythmia.

One control subject developed arrythmia and another oscillation. In one patient with IHD the heart rate did not rise above control after release and one patient with IHD had right bundle branch block. The time intervals were measured.

The beat-to-beat heart rate was measured throughout the manoeuvre and for 20 seconds after release.

Heart Rate Alone

76 subjects (52 controls and 24 with IHD) were selected in whom the heart rate increased during strain and was above control after release. All were in employment, or undergoing training at the time of the test. None showed clinical evidence of valvular heart disease and none were in clinical heart failure or receiving digitalis or a beta-blocking drug. All were in sinus rhythm and arrythmia did not occur. The resting diastolic blood pressure was below 101 mmHg. in all but two, 102 mmHg. in 1 and 110 mmHg. in 1.

The other 5 subjects did not fulfill these criteria. In 2 the heart rate did not accelerate during strain or after release, but bradycardia occurred. In 2 the heart rate accelerated during strain but fell by the end of strain and failed to recover after release. One patient was taking propranalol and digitalis.

The beat-to-beat heart rate was measured in the 81 subjects. In 76 subjects the time from the end of strain to the onset of fall

of heart rate, and from the onset of fall to the level of the resting heart rate, was expressed in whole beats rather than in fractions of a beat.

Time of Day

On one half-day a week I was relieved of regular duties as medical officer in a geriatric hospital although, for part of this study, remaining on call. The work was done on this half-day and also during evenings and week-ends, no particular time of day being reserved for the test. This may affect the results as the subjects were not in a basal state and also because there is a diurnal variation in the duration of the systolic time intervals. (Weissler et al, 1965).

RESULTS

GENERAL

(a) Phases of Heart Rate

The heart rate was measured from the electrocardiogram in the 81 subjects before, during and after the Valsalva manoeuvre and divided into phases.

The heart rate increased during strain. The heart rate at the end of strain was not greater than the maximum heart rate during strain, and was sometimes less. When the heart rate fell at the end of strain it usually rose again to above the control level after release. After release, either the heart rate increased to a point from which it started to fall or there was little change in heart rate until the onset of the fall, or the heart rate fell and rose, or fell early. Usually the fall in heart rate was sustained from its point of fall to below the control level but in some cases the fall was interrupted. Whether the fall was sustained or interrupted, the lowest point of the fall was below the average control level, even if only marginally, except in two cases. The heart rate tended to settle at its lowest point and this is termed the lowest settled state of the heart rate or L.S.S. The degree of fall below control at L.S.S. was maintained for more than 10 beats in the young athletes and in some cases in the other groups; in a few cases there was a further, temporary decrease. In the infarction/ischaemia group, the heart rate rose above control by the 10th beat after the L.S.S. in 2, and in 2 it rose and fell. The degree of fall below control varied.

The time from the end of strain to the point where the heart rate reached, or fell below, its control level varied. The beat in which the heart rate reached, or fell below, the control level is for convenience termed the returning beat of the heart rate.

The heart rate response was divided into the heart rate at control, maximum during strain, end of strain, onset of fall, returning beat, and at L.S.S.

The heart rate increased during strain and immediately after release in a manner similar to that described by Elisberg (1963) but differed in that the increase was greater in the group with ischaemic heart disease than in Elisberg's group with advanced heart disease in which there was no subsequent bradycardia. Bradycardia occurred in the IHD group. The heart rate usually returned to the average resting value on the 5th or on following beats in the control subjects and in Elisberg's (1963) control group bradycardia occurred after the 5th beat. In Elisberg's (1963) third group, of patients with cardiovascular abnormalities, bradycardia occurred after the 12th beat in one and after the 17th beat in one. In the present study two subjects in the IHD group did not return to their resting values. Nine subjects did not return to their resting values till the 12th beat or thereafter and one of these was a control subject. Flessus et al (1970) noted, in 11 healthy males aged 22 to 32 years, that 4 or 5 beats after release there was a precipitous fall in heart rate followed by a slight rebound. In the present study the degree of this rebound was most marked in the younger control subjects.

(b) Electrocardiogram

Cases are identified by group and number i.e. case 1-2 is case number 2 in group 1.

One case in the IHD group had right bundle branch block (case 5-18). In another the S-T segment rose during strain; this became more marked after release and then settled. (case 5-26).

Other changes occurred after release. In the 16-25 age group the P-R interval shortened temporarily in 3 cases and one case developed premature supraventricular beats (case 1-23). In 3 control subjects, aged 42-47, there was atrio-ventricular block for one beat. Flattening or inversion of the P wave occurred in both control subjects (6 cases) and in the IHD group (4 cases). In one case the T wave was inverted shortly after release (case 5-7). Ventricular premature beats were seen in one control subject and in 3 of the IHD group.

Shortening of the P-R interval in the young subjects and transient atrioventricular block in the older control subjects can be attributed to vagal stimulation. Increase in the S-T segment illustrates one hazard of the manoeuvre and ventricular beats another, but subjects with a prominent history of angina or who had frequent ventricular premature beats in the resting record were not asked to perform the manoeuvre.

(c) Heart Sounds and Carotid Pulse

The heart rate and systolic time intervals were examined in 32 records from 21 control subjects and 10 patients with IHD. The QS2, and therefore the PEP, was not measured during strain and the LVET was

measured, but not consistently. In 4 cases the PEP could not be measured at any point after release and in 1 case it could not be measured at the lowest settled state of the heart rate. The LVET was measured in 32 instances and the PEP in 28 cases after release but there was a delay before the measurements could be made, as illustrated below.

	Beats after Release at which Interval was First Measured.								
	1	2	3	4	5	6	7	8	
PEP (No. of Cases)	2	2	6	4	8	2	1	3	Total 28
LVET (No. of Cases)	3	3	7	7	8	2	1	1	Total 32

The delay in being able to make these measurements was disappointing and might have been improved if all the subjects had had practice but this would have meant taking time off from their work. However, in 28 cases the LVETc rose after it was first measured and the PEPc decreased so that the maximum change was probably observed.

When the results were assessed, one subject in the IHD group showed an abnormal heart rate response (case 5-11) and another gave an almost normal heart rate response (case 5-23a) but, when the test was repeated, developed ventricular premature beats after release (5-23b). The heart rate oscillated after release in one control subject (case 4-2) but this did not recur on either of the two occasions when the test was repeated using the electrocardiogram alone. In the subject with right bundle branch block the heart rate and systolic time interval responses did not correlate (case 5-18).

Cases were allocated to three divisions according to the type of response and availability of the measurements (Table 6). Division A comprises 15 control subjects and 6 patients with IHD where the heart rate increase during strain was maintained after release and in which the measurements of the PEP, LVET and QS2 were adequate. In the 4 control subjects and 3 patients in Division B the heart rate increment was similar and the measurements of the LVET were satisfactory. Division C contains 2 control subjects and 2 patients where the heart rate after release was abnormal or could not be correlated with the systolic time intervals.

Division A - Cases 1-1, 1-3, 1-5, 1-6, 1-21, 1-22, 1-24, 2-3, 2-4, 2-7, 3-4, 3-7, 3-9, 4-1, 4-8, 5-6, 5-10, 5-23a, 5-26, 5-27, 5-29.

Division B - Cases 1-16, 3-1, 3-5, 4-9, 5-2, 5-24, plus 5-23b.

Division C - Cases 1-23, 4-2, 5-11, 5-18.

UNCORRECTED SYSTOLIC TIME INTERVALS

(a) Resting Values

The mean resting values for the pre-ejection period (PEP), left ventricular ejection time (LVET), total systole (QS2) and the PEP/LVET ratio are given in Table 2 for 21 control subjects and 10 patients with IHD (one of the patients has two records).

The resting values for the PEP and LVET were in the same range as that given by Flessas et al (1970) for similar subjects. In the normal subjects the PEP/LVET ratio corresponded with that given by Weissler et al (1969) for normal subjects.

Of all subjects, the average QS2 was 378 msec. and the range from 323 to 426 msec. Weissler et al (1968) tabulate the QS2 intervals for males in heart failure, which they found were similar to those of normal males, and in their study the average QS2 was 363 msec. for males in heart failure and the range from 326 to 409 msec.

(b) During Strain and After Release

Beat to beat changes in the PEP and LVET were not analysed. The LVET shortened during strain in all groups and increased after release beyond the control level in all groups, which is in agreement with the measurements of Flessas et al (1970) (Table 3). These authors noted no significant trends in the PEP after release on beat-to-beat analysis but, from their Fig. 2B, it appears that there was an overall decrease in the PEP after release and this is also comparable with the present study.

CORRECTED SYSTOLIC TIME INTERVALS

(a) Resting Values

The heart rate and the systolic time intervals, corrected for heart rate, are shown in Tables 4a and 4b. The average QS2c was 544.6 msec. and the range from 500.3 to 583.2 msec.

To compare these results with those of Weissler et al (1968) the systolic time intervals, corrected for heart rate, were calculated from their figures by means of their regression equations. In their study the normal males had an average QS2c of 546 msec. and the males with heart failure had an average QS2c of 547.9 msec. and the range was from 509.4 to 589.5 msec. (Table 4c).

The figures in this study are therefore comparable with those of Weissler et al (1968) but, although the average QS2c was the same, the longest QS2c intervals in the young athletes (Group 1, Nos. 1, 3, 5, and 6) were the same as the shortest QS2c intervals in Groups 3, 4, and 5. The athletes had short PEPc and QS2c intervals, indicating relatively large resting stroke volumes and rates of flow which may have been due to an enhanced ventricular performance or less resistance to flow.

Four cases had long PEPc and short LVETc intervals. One was a control subject (case 4-9) and 3 were patients with IHD (cases 5-23b, 5-24, 5-27). These intervals are similar to some of the cases with heart failure investigated by Weissler et al (1968) and all had poor responses. Most of the cases with heart failure in their study had longer PEPc intervals. In four cases a long PEPc interval (over 140

msec.) was not associated with a particularly short LVETc (cases 1-22, 5-10, 5-11 and 5-26). Three cases had a long LVETc (over 440 msec.) and a long QS2c (cases 3-7, 4-2 and 5-29).

There are thus differences in the resting records particularly between healthy active young men and subjects with ischaemic heart disease. But the resting record of a healthy young man (case 1-22) is similar to that of some subjects with ischaemic heart disease. Many of the cases appear to show values for the PEPc and LVETc intermediate to those for normal subjects and patients with heart failure studied by Weissler and associates, but this may in part be due to the conditions of the test. In Weissler's investigations all subjects were in a basal state, fasting and all observations were made at the same time of day. The records in this study were taken at any time of day, without relation to meals, and although the subjects had rested for 30 minutes some were anxious about their physical condition or in their ability to perform the test satisfactorily.

(b) <u>During Strain</u>

Of 32 cases, the LVETc could be measured at some point during strain in 21 (Table 5). In 2 cases the LVETc fell less than 20 msec. below the control level. In the other cases the LVETc fell 30 to 100 msec. below the control level. The LVETc decreased during strain. Decrease in the LVETc is due to a decrease in stroke volume and/or an increase in the mean rate of flow. The heart rate increased during strain (Table 8).

(c) After Release

The measurements of the heart rate, LVETc and PEPc are given in Table 6. Contours for each parameter were plotted for each subject and examples are shown in Fig. 2.

In most cases the first measurement of the LVETc and of the PEPc coincided but in some cases the first measurement of the LVETc preceded that of the PEPc. In the 4 cases where the PEPc could not be measured, the first measurement of the LVETc was made at the 3rd, 4th, 5th and 6th beats after release. In 28 cases the LVETc rose after it was first measured and the PEPc decreased. In 4 cases the maximum LVETc was the first LVETc measured and it was measured 3 to 6 beats after release.

The LVETc could be measured in 12 cases between the end of strain and the onset of fall of heart rate when the heart rate was steady or rising. The LVETc increased in each case. The PEPc decreased in 6 of these cases, did not change in 2, fell and rose in 1, varied in 1, and could not be measured in 2 (A).

The LVETc could be measured in 14 cases where the onset of fall of heart rate preceded the maximum LVETc. The LVETc increased in each case as the heart rate fell from the onset of fall to the beat of the maximum LVETc. The PEPc decreased in 6 of these cases, rose in 2 and could not be measured in 6 (B).

(A) PEPc decreased in cases 1-6, 1-21, 1-22, 2-7, 5-18, 5-23b; did not change in 1-5, 5-29; fell and rose in 1-24; varied in 3-9; not measured in 1-23, 2-3.

(B) PEPc decreased in cases 1-22, 2-4, 2-7, 3-4, 4-8, 5-2; rose in 3-7, 4-1; not measured in 1-16, 1-23, 3-1, 3-5, 4-9, 5-24.

Thus the LVETc increased up to a maximum whether the heart rate was steady, rose, or had begun to fall as the output per beat began regularly to exceed the outflow.

As the maximum LVETc coincided with, or followed, the point where the output had increased from end of strain, exceeding outflow, the PEPc might have been expected to decrease but did not do so consistently. But, following the maximum LVETc, the PEPc decreased below its first measurement in all 28 instances. After its first measurement the PEPc decreased without interruption in 12 cases; rose above the first measurement and fell below it in 5 cases; and fell, rose, and fell below the first measurement in 11 cases. The degree of maximum decrease is shown in Table 7.

The maximum decrease from control after release in the initial LVETc and the maximum increase in the initial PEPc were not consistently observed.

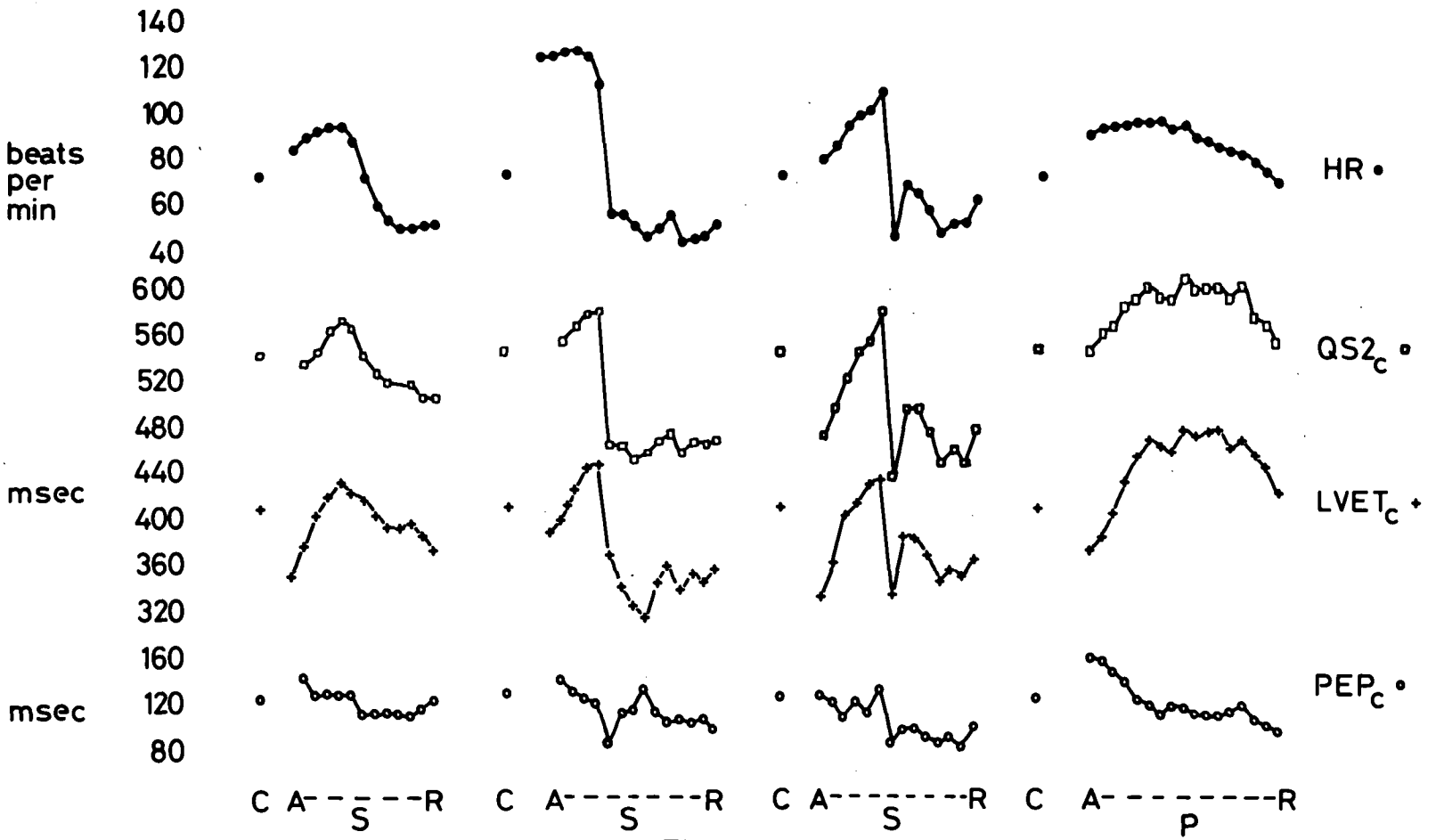


Figure 2

Examples of control (C) and beat-to-beat values after release (A---R) of heart rate, QS2, LVETc and PEPc in three control subjects (S) and a patient with ischaemic heart disease (P).

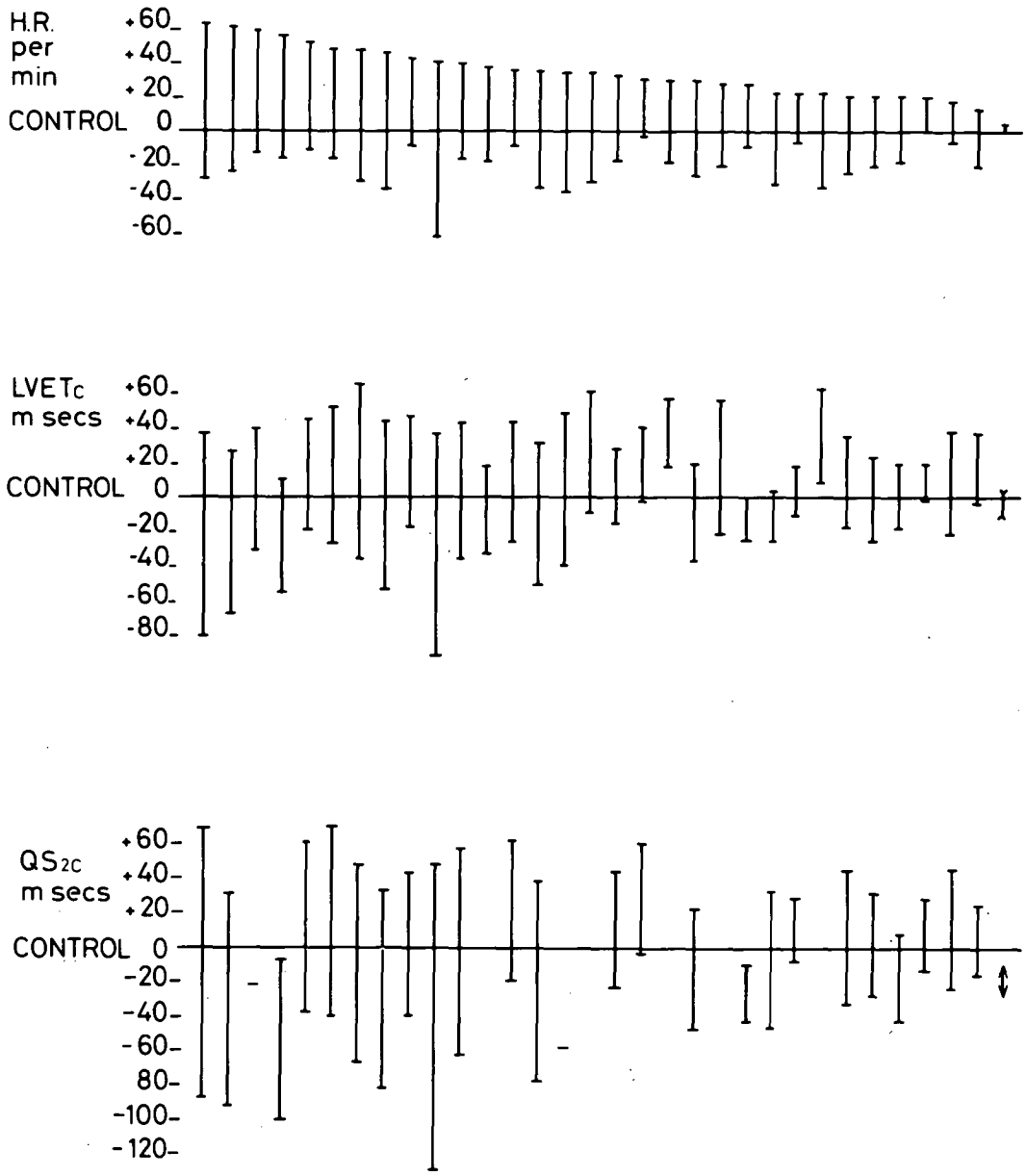


Fig.3

Change from control and degree of fall in heart rate LVETc and QS2c (from Tables 8 and 9).

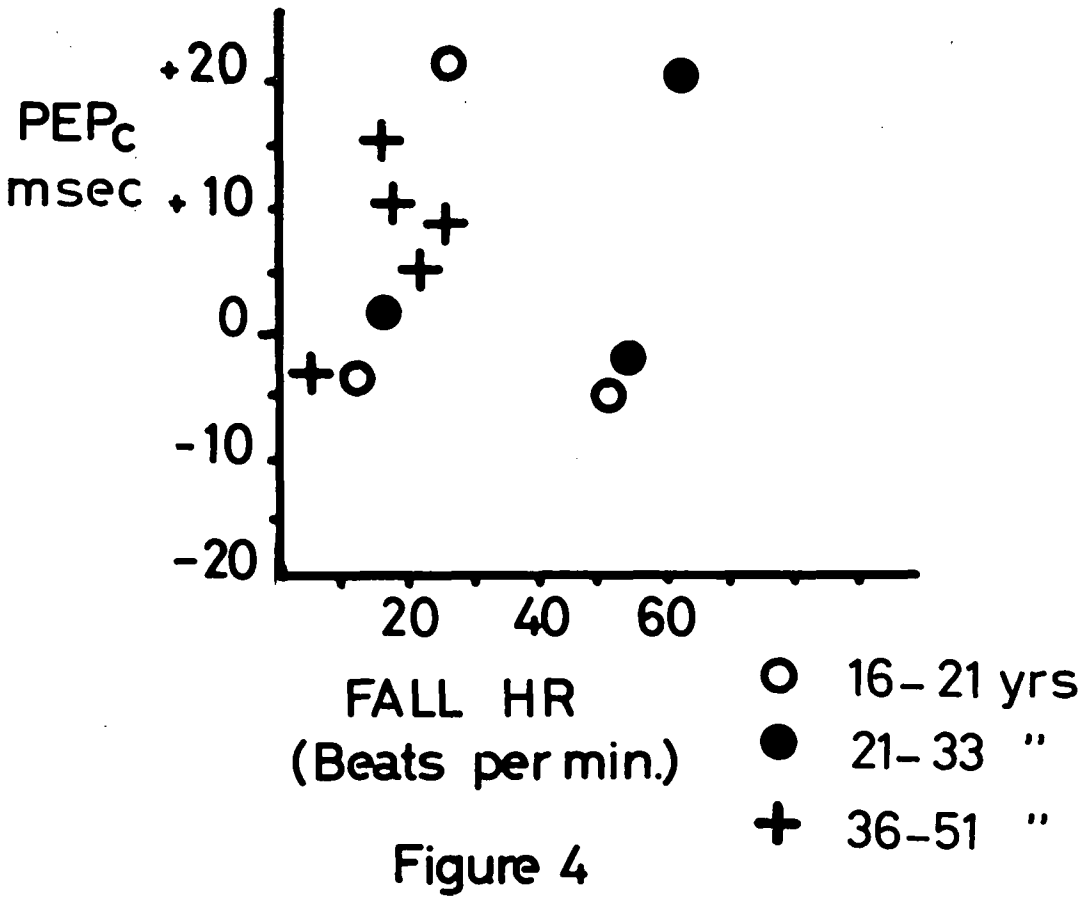


Figure 4

Change in PEPc in one beat and fall in heart rate in the following beat in eleven control subjects. Symbols. (From Table 10).

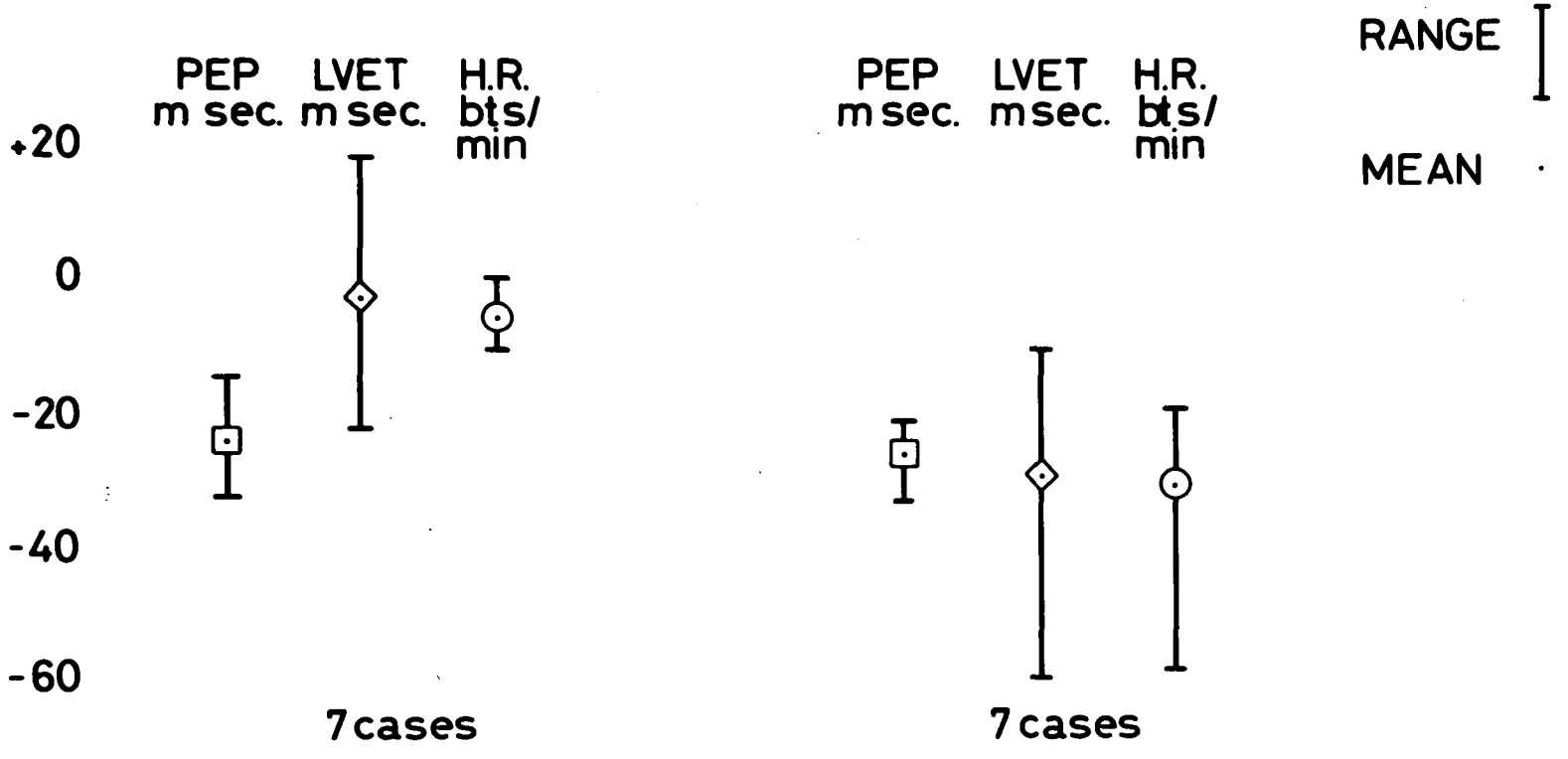


Fig.5

Change from control at settled PEPc in fourteen cases divided into two groups according to the degree of fall of heart rate below control (From Tables 11 and 13).

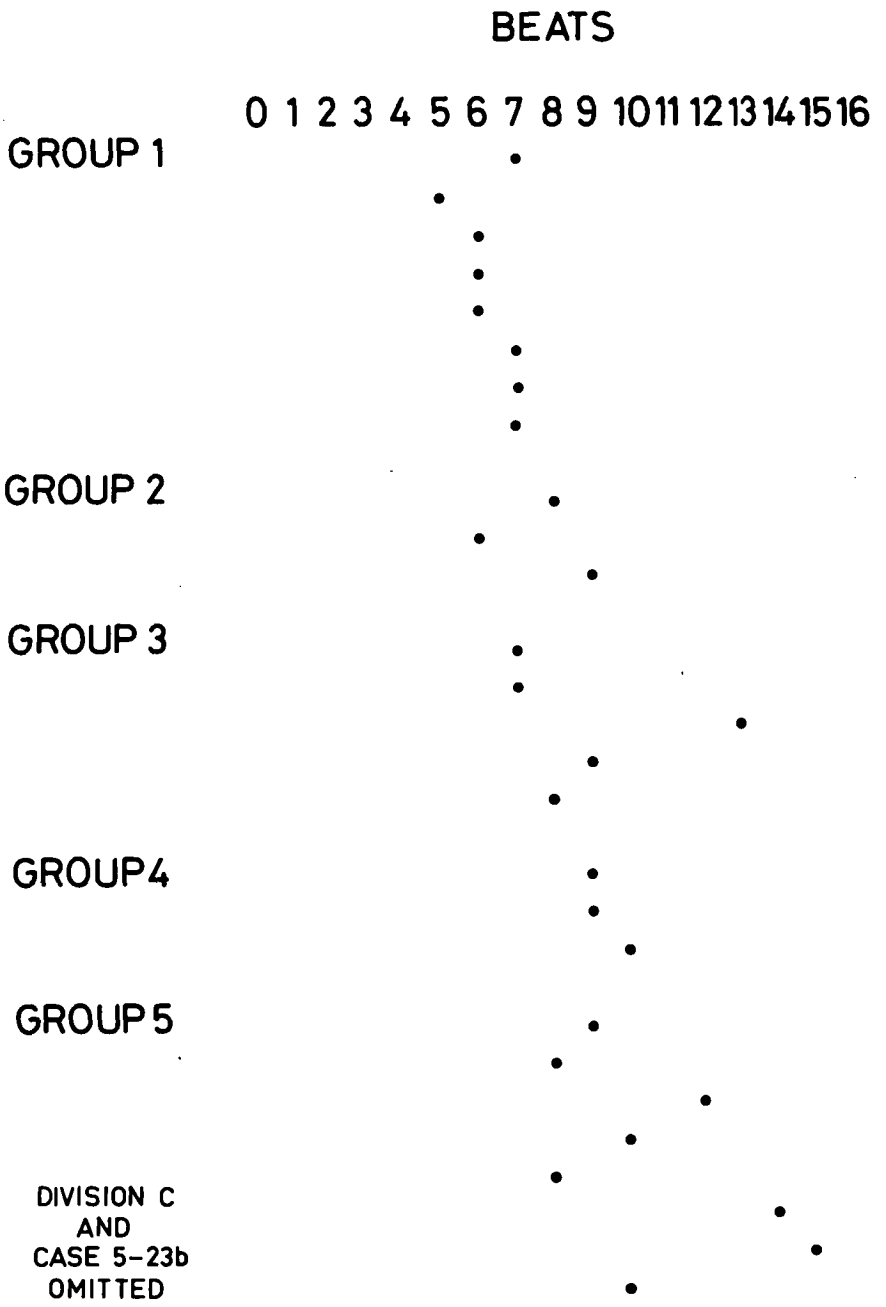


Fig.6

The time from end of strain to the return of heart rate to control (returning beat - RB) from Table 12.

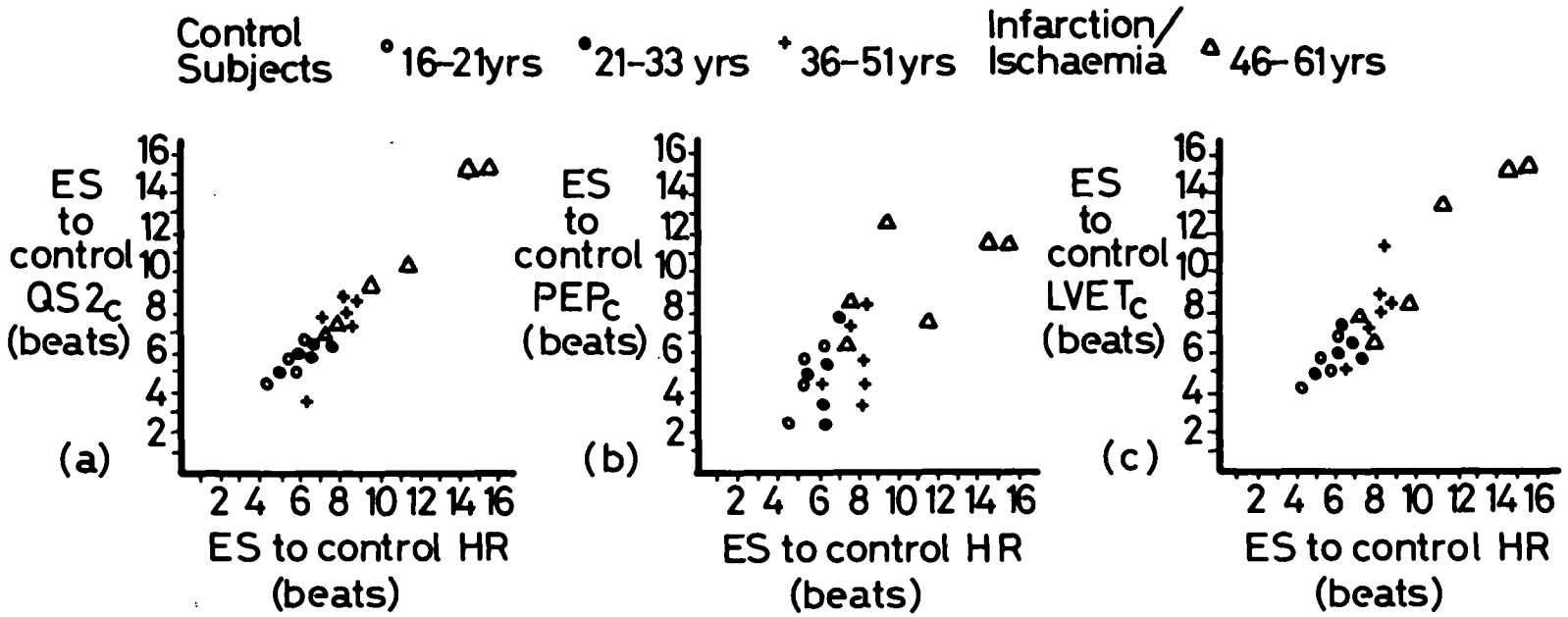


Figure 7

The relationship between the return to control of the heart rate and of the QS2c (Fig.7a) PEPc (Fig.7b) and LVETc (Fig.7c). Division A. Symbols. (From Tables 12 and 15).

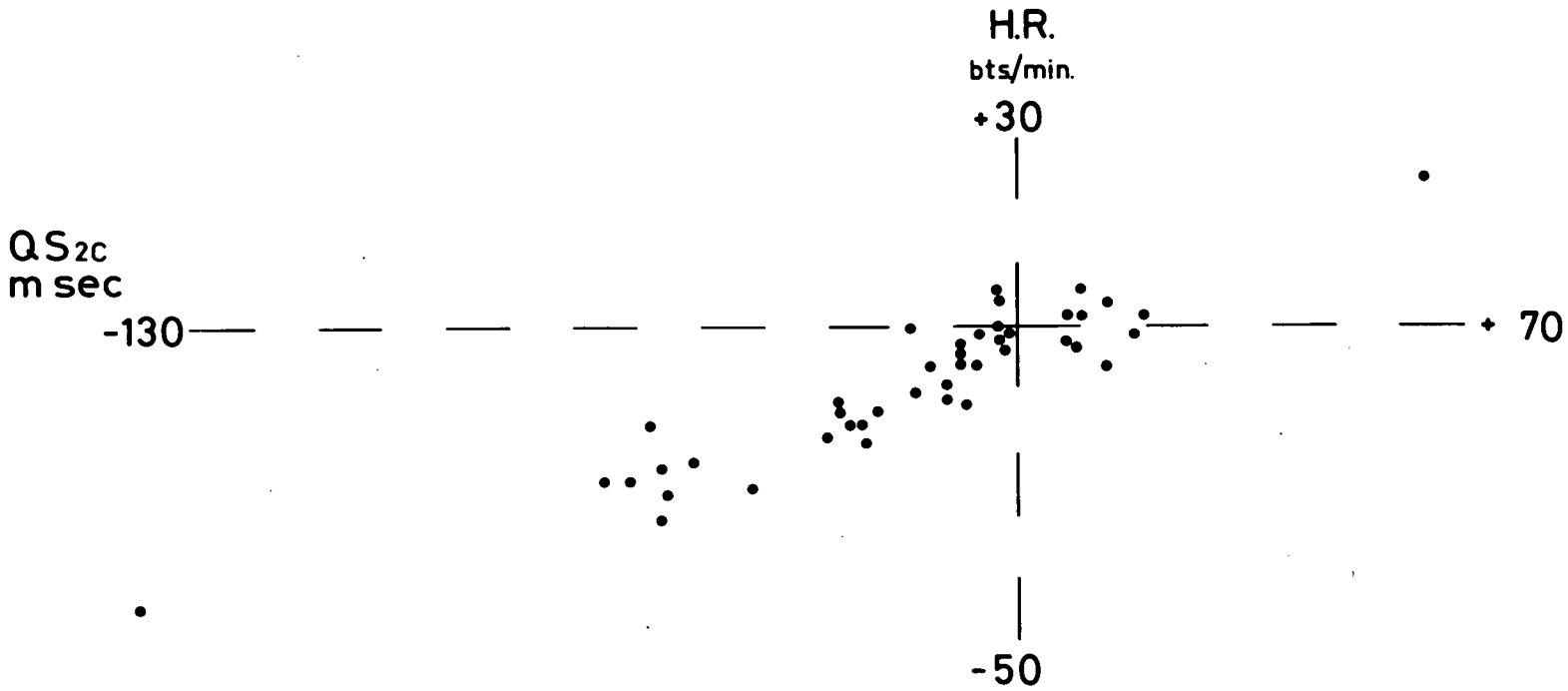


Fig.8

The change in heart rate and in the QS2c between the returning beat H.R., settled PEPc and L.S.S. (From Table 11).

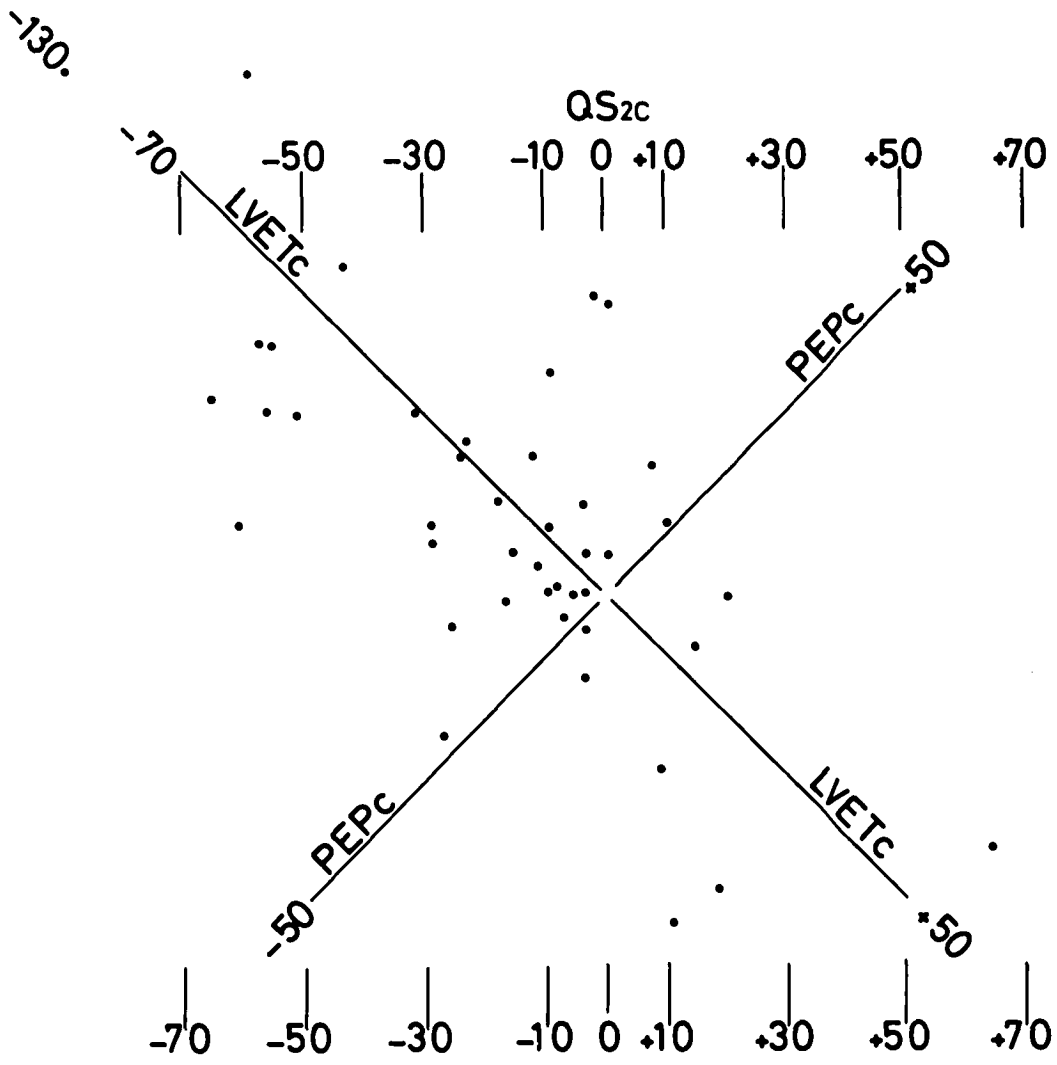


Fig.9

The change in the PEPc and LVETc between the returning beat H.R., settled PEPc and L.S.S. ± QS2c = ± PEPc plus ± LVETc. From Table 11.

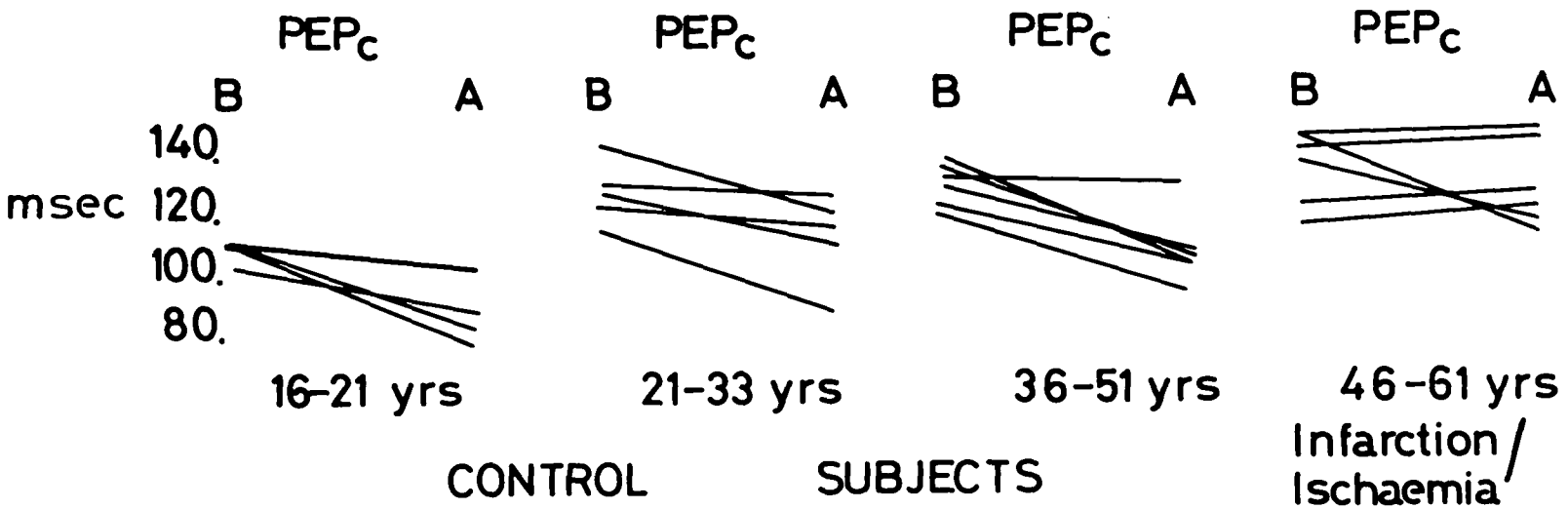
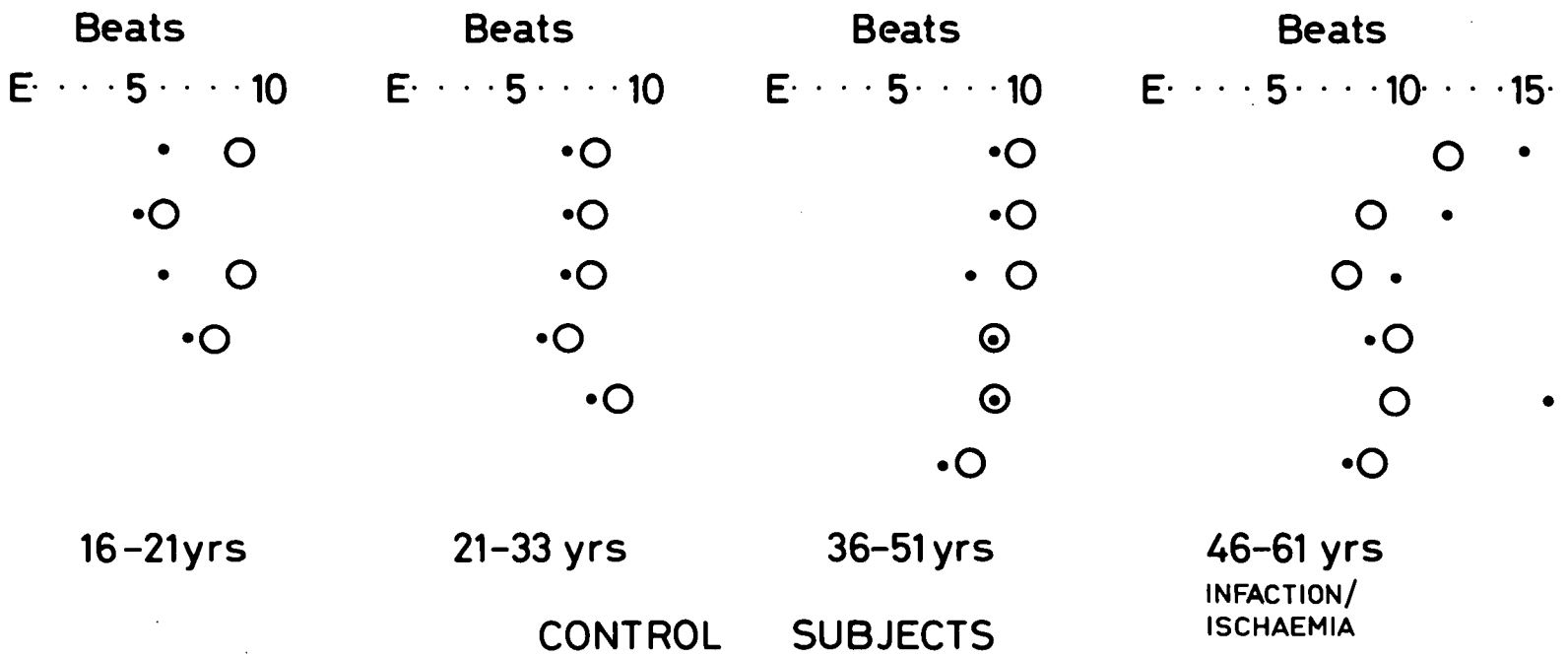


Figure 10a

Division A from Table 13

Degree of change in the PEPc from the value before the manoeuvre (B) to where it 'settled' after the manoeuvre (A). Division A. Tables 13 and 14.



DIVISION A FROM TABLE 13

Fig.10b

The number of beats from the end of strain (E) to the beat in which the heart rate falls to control (•) and to the settled PEPc (O) Subjects in the same order as in Fig.10a. Tables 13 and 14.

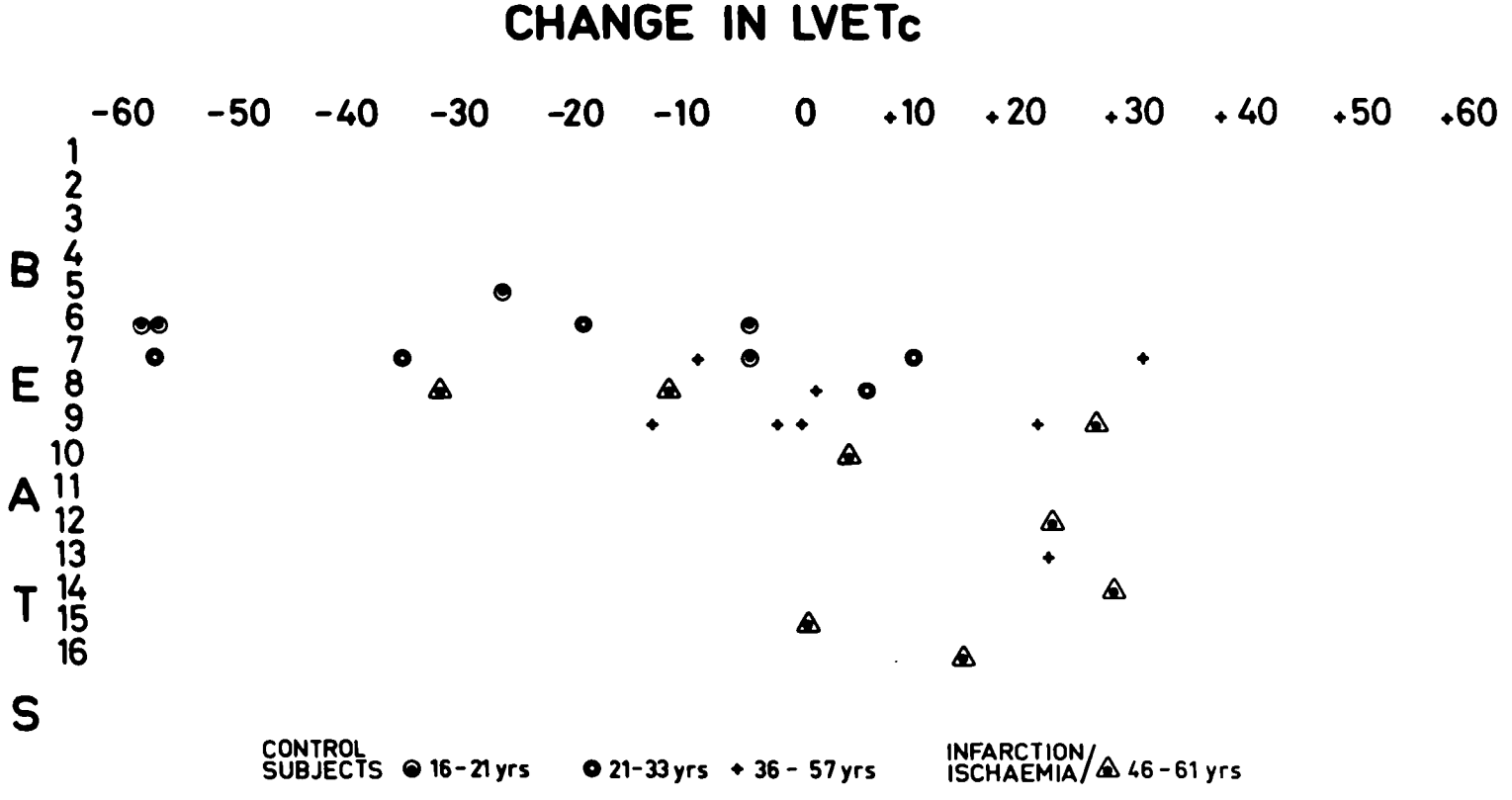


Fig.11

Number of beats from the end of strain to the control heart rate and the change from control in the LVETc at the returning beat (From Table 12).

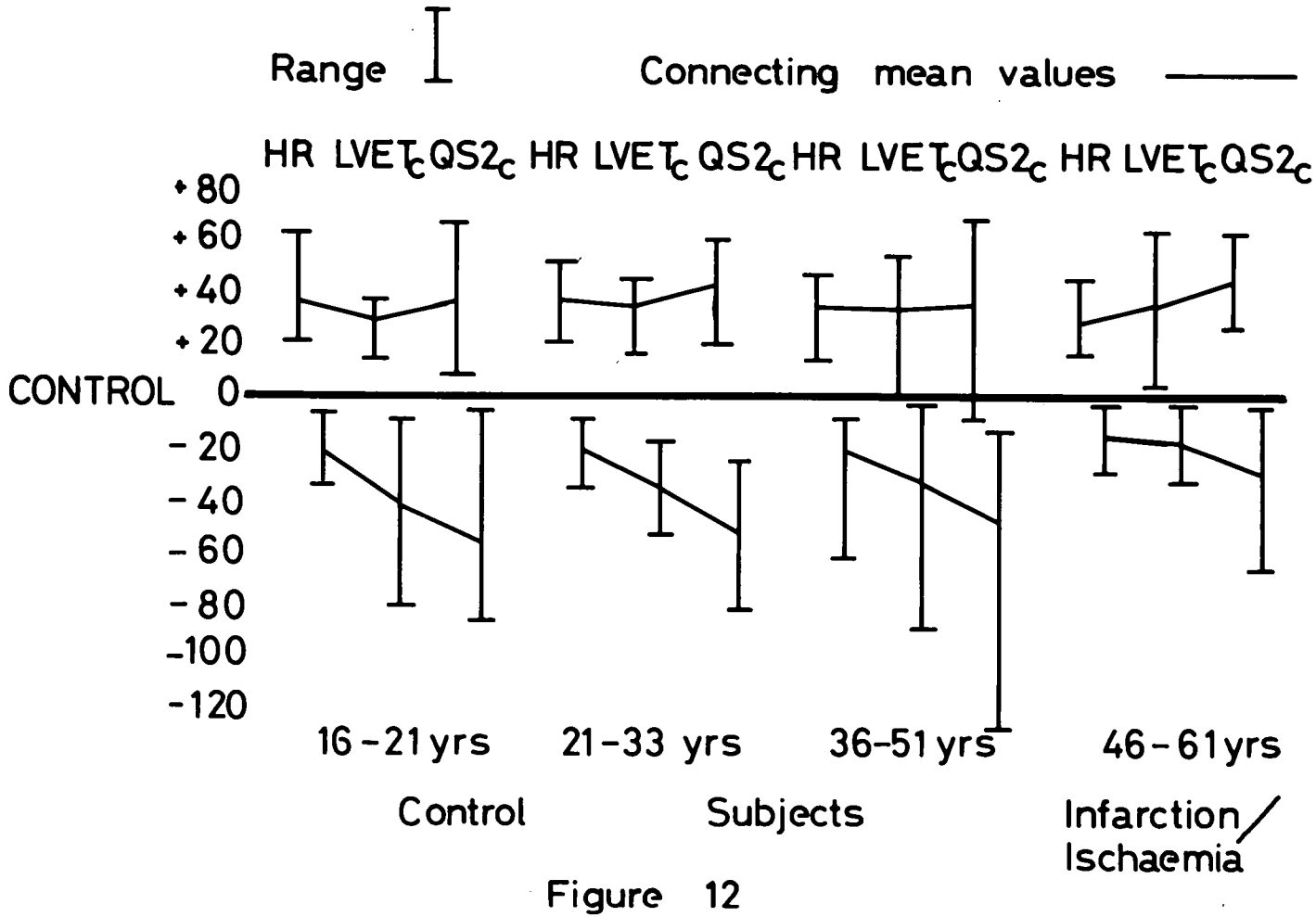


Figure 12

Rise in heart rate, LVETc and QS2c from control and subsequent fall below control. Heart rate (beats per minute) taken at onset of fall and lowest settled state HR. (LVETc and QS2c in msec.) Taken at max. LVETc and lowest settled state HR. Division A.

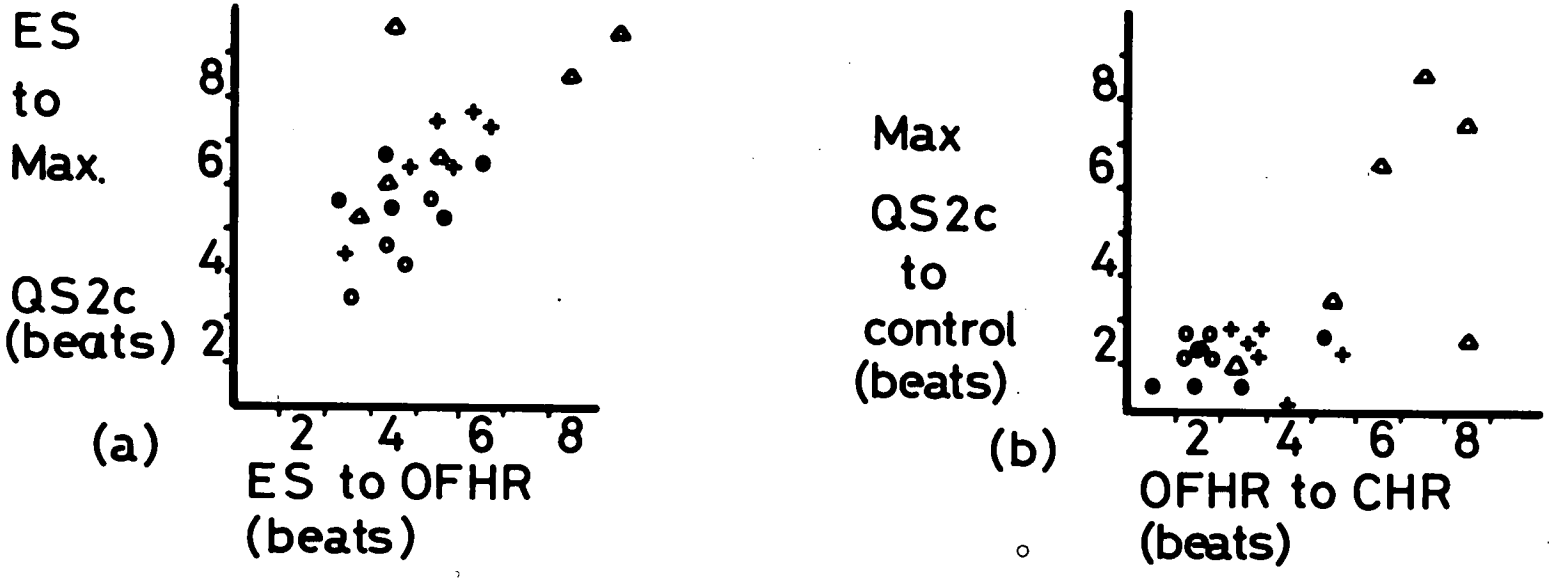


FIGURE 13
(symbols as for Fig 7)

Rate of change. The time from the end of strain (ES) to onset of fall of heart rate (OFHR) and to maximum LVETc and QS2c (Fig.13a) and from there to the control levels of heart rate (CHR) and QS2c (Fig.13b) Division A.

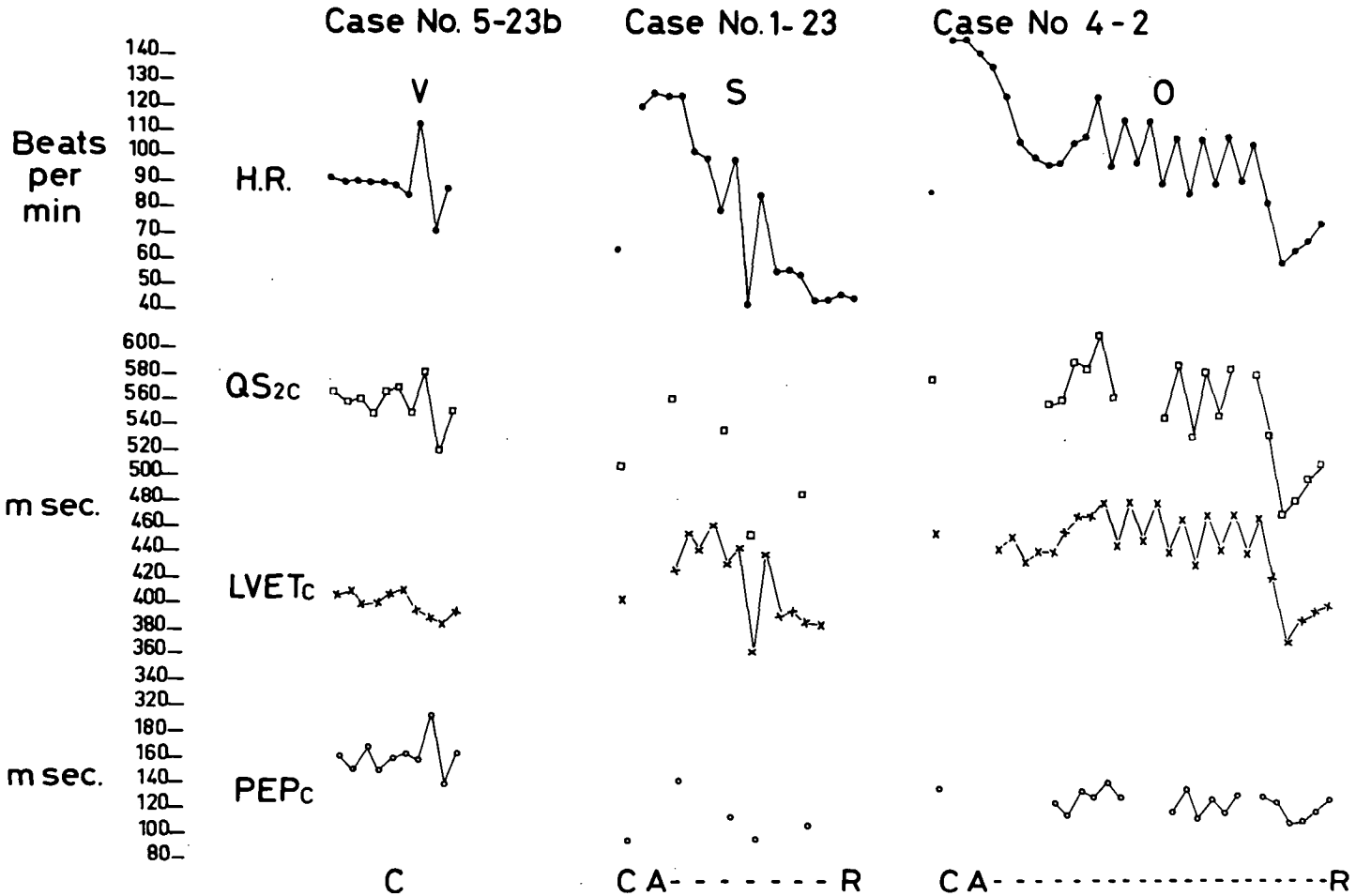


Fig.14

Systolic time intervals accompanying a ventricular premature beat (V) supraventricular beats (S) and oscillation of heart rate (O).

ANALYSIS OF HEART RATE AND CORRECTED SYSTOLIC TIME INTERVALS AFTER RELEASE

The response to the Valsalva manoeuvre has not previously been analysed using the systolic time intervals corrected for heart rate. The method of analysis and summary are presented first, followed by a more detailed account.

(a) Method and Summary

It had been proposed to interpret the results for individual cases in terms of overshoot of volume, rate of flow and momentum and to relate these to the time the heart rate returned to normal. Volume overshoot can be indicated by reduction in the PEPc from control; rate of flow overshoot can be shown by reduction in the LVETc from control if there was no volume overshoot, or the same or a reduced LVETc if there was a volume overshoot; and an overshoot of momentum can be represented by reduction of the QS2c whether caused by reduction of the PEPc, or LVETc, or both.

The heart rate increment after release was taken as proportional to the increase in resistance to flow. It was hoped to assess left ventricular performance by comparing the overshoot responses with the heart rate increment, but the time intervals altered to an unexpected degree and in a manner suggesting they were affected by change in resistance and pressure.

In individual cases the heart rate, LVETc and QS2c rose above their resting values and then fell, but the changes were not proportional. (Fig. 2 and 3. Tables 8 and 9). It could not be

determined whether the rise in the LVETc and QS2c in individual cases was due to increase in stroke volume and/or decrease in rate of flow, or whether the fall was due to reduction in afterload and/or increase in left ventricular performance. Thus, the lowest value of the PEPc was not related to any particular phase of the heart rate (Table 7), the PEPc being apparently affected by the rapid rise and fall of pressure (Fig. 4 and Table 10) and the LVETc fell more than the PEPc when the heart rate had also fallen (Fig. 5; Tables 11 and 13) i.e. when the afterload had decreased. Further, although some of the older control subjects and some of the patients with ischaemic heart disease tended to take more time from the end of strain to the control heart rate than did the young control subjects, some subjects in all groups took similar times (Fig. 6, Table 12).

But, there was a close relationship between the times taken by the heart rate and the QS2c to reach their resting values (Fig. 7, Tables 12 and 15), and, following this, the heart rate and QS2c tended to rise and fall together (Fig. 8, Table 11), although changes in the QS2c were due to changes in the PEPc and/or the LVETc (Fig. 9, Table 11). Factors influencing the time of return of heart rate were found by examining the PEPc at a point where it ceased to change or 'settled'.

When the PEPc at the 'settled' PEPc had not decreased from its resting value or had settled before the heart rate returned to control, or was not small - i.e. when there was no volume overshoot, or the stroke volume had ceased to increase although the heart rate had not fallen, or the stroke volume was not relatively large - the heart rate took longer to return to its resting value than when the

PEPc was small. (Figs. 10a and 10b, Tables 13 and 14). Inability or slowness to reduce the LVETc - i.e. to overcome the resistance to flow - was also associated with delay in the return of the heart rate (Fig. 11, Table 13). And the patients with ischaemic heart disease, compared with the younger athletic group, had a greater rise in the LVETc and QS2c relative to the heart rate increment and a lesser fall - i.e. were most adversely affected by the increase in resistance to flow (Fig. 12). But, in individual cases able to attain a greater stroke volume, overshoot, and increase in rate of flow, the heart rate did not return to its resting value earlier than in subjects less able. (Table 13).

However, when the time from the point of fall of the QS2c and heart rate to their resting values was taken, a better differentiation was obtained (Fig. 13 and Fig. 2). As the QS2c at its maximum had been shown to be affected by pressure, the time from the point of fall of heart rate to control was examined in all cases in the study. (Table 16).

(b) Decrease in the PEPc (Table 7)

The PEPc decreased after its first measurement. The lowest value of the PEPc was not related to any particular phase of the heart rate and occurred at the maximum fall of heart rate in one beat in 4 cases, after it in 3 cases, later, but before the lowest settled state of the heart rate (L.S.S.) in 8 cases, and at the L.S.S. in 12 cases. The rate and degree of decrease could not be measured as the first measurement could not be made at the same beat in each case. The maximum PEPc occurs soon, perhaps immediately, after release.

(c) Rise in H.R., LVETc and QS2c from Control (Table 8 and Fig. 3)

The maximum LVETc was measured in 32 instances. The maximum PEPc could not be measured. In 25 cases the PEPc could be measured in the same beat as the maximum measured value of the LVETc to give the maximum QS2c (exceptions, cases 1-23, 3-1, and 5-2).

When the heart rate at the end of strain was less than the maximum heart rate during strain it had increased by the onset of fall of heart rate to or beyond the maximum value during strain, except in 3 cases (3-4, 5-23b, and 5-11). At the onset of fall, case 3-4 was 28 beats above the control value and case 5-23b was 21 beats above control. Case 5-11 was only 5 beats above control, having fallen 25 beats from the maximum value during strain, and was therefore an abnormal response.

In all but 2 cases the LVETc rose above its control value, the rise varying from 2.4 to 65 msec. (exceptions, cases 3-4 and 5-11).

In all but 3 cases the QS2c rose above its control value, the rise varying from 9.2 to 69.7 msec. (exceptions, cases 3-4, 5-11 and 5-18).

The rise in the LVETc was due to increase in stroke volume over control and/or decrease in mean rate of flow but these two factors could not be distinguished as, on further analysis, (Table 10), the PEPc at this point could not be relied on to indicate changes in stroke volume.

(d) Fall in H.R., LVETc and QS2c to L.S.S. and Change from Control at L.S.S. (Table 9 and Fig. 3)

The lowest value of the LVETc was at the lowest settled state of the heart rate (L.S.S.) in 26 cases, before this was reached in 2 cases, and at the maximum fall of heart rate in one beat in 3 cases. (From Table 6, case 5-11 excluded). Table 9 shows the fall to the L.S.S.

The LVETc was measured in 32 instances at its maximum and at L.S.S. The QS2c was measured at its maximum in 25 cases and at L.S.S. in 27 cases. In 31 cases the fall in heart rate was accompanied by a fall in the LVETc and in 24 cases by a fall in the QS2c (exception, case 5-11). The fall in heart rate varied from 21 to 101 beats; the fall in the LVETc from 20.9 to 128.3 msec; and the fall in the QS2c from 32.5 to 176.8 msec. The fall in the QS2c was always greater than the fall in the LVETc although the difference varied. The fall in the LVETc was therefore associated with an increase in the mean rate of flow. Neither the fall in the LVETc or in the QS2c were proportional to the fall in heart rate in individual cases. Also, the change from control at L.S.S. in heart rate, LVETc, QS2c and PEPc were not proportional in individual cases. (The settled PEPc is defined in Table 11).

(e) PEPc and S1-AO at Maximum Fall H.R. (Table 10 and Fig. 4)

The relation of the change in the PEPc to the fall in heart rate was examined. The actual PEPc is shown for comparison with the actual S1-AO interval (first heart sound to aortic opening, see METHOD), in 24 cases.

Between the PEPc and the S1-A0 intervals there was no correspondence between values and little correspondence between beat to beat changes except in cases 1-24, 3-9 and 5-23a.

In 11 of the control subjects the PEPc fell only slightly, or rose, before a fall in heart rate even when the fall in heart rate was considerable (Fig. 4).

Thus (Table 10) the PEPc rose before a large fall in heart rate in cases 1-24, 3-7, 4-1 and possibly 1-1. The PEPc rose before a smaller fall in heart rate in case 1-3 and before a small fall in heart rate in case 5-29. The PEPc rose and fell while the heart rate was falling in cases 3-9 and 5-26. The PEPc mainly fell while the heart rate was falling in case 5-27. But there was an early large fall in the PEPc with a small fall in heart rate in case 4-8.

In 16 cases the PEPc fell in the same beat as the maximum fall in heart rate and in 5 cases both falls were large (cases 1-24, 1-22, 1-1, 1-5 and 4-1); the PEPc was not measured in 5 cases at the beat of the maximum fall in heart rate and the PEPc did not fall at this beat in the remaining 3 cases (1-3, 1-6, 3-7). In case 1-3 the PEPc, which had risen, fell in the next beat. Case 1-6 had two similar falls of heart rate and the PEPc fell with the second, and then the heart rate and the PEPc both rose. In case 3-7 three falls of heart rate were associated with falls of the PEPc but the last, and largest, fall of heart rate was not; the largest fall of heart rate occurred after the heart rate had passed its control level.

The PEPc rose more than 20 msec. after it had fallen and then fell again in cases 1-22, 1-5 and 1-6.

Thus the change in the PEPc bore no consistent relation to the change in the heart rate in a beat. If the PEPc was not affected by rise of pressure then it would decrease with the increase in stroke volume that caused the pressure rise, but the PEPc increased with the rise of pressure that preceded a large fall in heart rate in one beat. It is possible that smaller rises of pressure would prevent the PEPc from decreasing.

If the PEPc was not affected by fall of pressure then it would not rise after it had fallen, and fall again, unless the stroke volume increased from the end of strain, decreased for one beat and again increased.

The PEPc may therefore be affected by the rapid rise and fall of blood pressure at this period and is unreliable as an indication of changes in stroke volume.

There was evidence of a difference in pattern in the beat-to-beat falls of heart rate between 7 of the 9 cases in group 5 (the IHD group) and the other groups. Although the cases in groups 1 to 4 showed marked differences in the degree of fall of heart rate in one beat at, or just before, the returning beat, the falls were not small. The smallest falls in heart rate occurred in cases 2-7, 5-11, 5-26, 5-27 and 5-29. In case 5-6 the largest fall was two beats before the returning beat, case 5-10 had three similar falls before a smaller fall at the returning beat, and case 5-18 had relatively large, early and intermittent falls.

(f) Change in Time Intervals between Returning Beat H.R., Settled PEPc and L.S.S. (Table 11, Fig. 8 and Fig. 9)

After the PEPc fell there was a point where it ceased to change, even if only temporarily, and appeared to be minimally affected by changes in pressure. In 25 cases this point was termed the 'settled' PEPc and was taken from Table 6. When two beats had a similar value, the lesser was chosen. Changes in the PEPc and other indices were then examined before and between two relatively settled states of the PEPc i.e. at the settled PEPc and at L.S.S.

In 20 cases the PEPc at the 'settled' PEPc differed from an adjacent PEPc by less than 4.5 msec. Of the other 5 cases, the PEPc fell 6.4 msec. from the previous beat in one (case 1-6) and the heart rate fell 6 beats. From the 'settled' PEPc to the next beat, the PEPc rose 14.4 msec. in case 3-1 and 11.6 msec. in case 5-11. In case 5-23b the PEPc 'settled' at the lowest settled state of the heart rate (L.S.S.). In case 5-23a the PEPc decreased progressively to the point where the heart rate began to settle, and this was taken as the 'settled' PEPc as the next two beats could not be measured. In this case the PEPc rose by 14.8 msec. from the 'settled' PEPc to the PEPc at the L.S.S.

In 17 cases the PEPc settled after the beat in which the heart rate reached, or fell below, its resting value (termed the returning beat of the heart rate). In 3 cases the PEPc settled at the returning beat and in 4 cases before the returning beat of the heart rate.

Measurements were taken with reference to the QS2c. When the QS2c did not vary more than $\pm$ 5 msec. it was reported as not changing.

Change from Return Beat H.R. to Settled PEPc

In 4 cases there was no change in the QS2c and the heart rate changed -1 to +6 beats. (Cases 1-6, 1-22, 3-4 and 3-9).

In 3 cases the QS2c fell from 6.6 to 16 msec. and the heart rate fell 3 to 10 beats. (Cases 2-3, 2-7 and 5-6).

In 4 cases the QS2c rose, mainly due to a rise in the LVETc. In one of these the rise in the QS2c was slight (+9.7 msec.) and the heart rate fell 3 beats. In two the QS2c rose 10.6 to 14.4 msec. and the heart rate rose 4 to 6 beats. But in one case the QS2c rose +64.4 msec. and the heart rate rose 24 beats. (Cases 2-4, 1-3, 1-5 and 1-24).

In 3 cases the QS2c fell, mainly due to a fall in the LVETc. In two of these the QS2c fell from 11.3 to 28.2 msec. and the heart rate fell 11 to 12 beats. But in one case the QS2c fell 128.4 msec. and the heart rate fell 44 beats. (Cases 1-1, 1-21 and 3-7). In one case the LVETc and the heart rate fell. (Case 3-1).

In one case the QS2c fell 26.5 msec. mainly due to a fall in the PEPc and the heart rate fell 15 beats. (Case 5-23a). In one case a large fall in the QS2c was due to falls in the LVETc and the PEPc and the heart rate fell. (Case 5-23b).

Change from Settled PEPc to L.S.S.

In 4 cases there was no change in the QS2c and the heart rate changed -6 to +5 beats. (Cases 2-3, 2-7, 4-1 and 5-6). In one case

there was a slight fall in the QS2c and the heart rate fell 12 beats. (Case 1-22).

In 4 cases the QS2c rose from 8.2 to 20.2 msec. and the heart rate changed -1 to +2 beats. The rise in the QS2c was due to a rise in the PEPc, or in PEPc and LVETc, or due to a rise in one being greater than a fall in the other. (Cases 1-6, 1-5, 3-7 and 5-23a).

In 9 cases the QS2c fell from 9.4 to 58.5 msec. and the heart rate fell 4 to 21 beats. In 8 of these cases the fall in the QS2c was mainly due to a fall in the LVETc and in one mainly to a fall in the PEPc. (Cases 1-1, 1-3, 1-24, 2-4, 3-1, 3-4, 4-8 and 5-18).

Change from Settled PEPc to Return Beat H.R. and to L.S.S.

From the settled PEPc to the L.S.S. the QS2c fell in the 5 cases. When the fall in the QS2c was due, or mainly due, to a fall in the LVETc, the QS2c fell from 22.4 to 121 msec. and the heart rate fell 13 to 50 beats in 4 cases. In one case a fall of 22.1 msec. in the QS2c was mainly due to a fall in the PEPc and the heart rate fell by 1 beat. (Case 5-27).

Summary

In 9 instances the QS2c did not change and the heart rate changed -6 to +5 beats. In 7 instances the QS2c rose from 8.2 msec. to 20.2 msec. and the heart rate rose from 2 to 6 beats in five and fell from 1 to 3 beats in two. A large rise in the QS2c was accompanied by a large rise in heart rate.

In 3 cases the QS2c fell from 22.1 to 26.5 msec., mainly due to a fall in the PEPc, and the heart rate fell from 1 to 15 beats. In 21 instances the QS2c fell, mainly due to a fall in the LVETc, and the heart rate fell. The falls were not proportional.

The heart rate and the QS2c were therefore associated in that they tended to rise and fall together, but the degree of rise and fall were not associated.

A fall in the QS2c may be associated with a fall in the PEPc and/or a fall in the LVETc. The fall in heart rate was most often associated with a fall in the LVETc, suggesting an increase in rate of flow due to a reduction in afterload.

(g) Time of Return to Control and Change from Control at Returning Beat. (Table 12)

Return of Heart Rate (Fig. 6)

11 cases took 5-7 beats for the heart rate to return to, or below, its resting value; all were control subjects; all the subjects in the 16-25 age group were included as were 3 subjects aged 33 to 47 years.

8 cases took 10 or more beats; 6 were in the IHD group and 2 were controls; one of the controls had obstructive airway disease and the other, aged 57, had a resting B.P. of 130/100 mmHg.

4 cases took 8 beats, 2 IHD and 2 controls. 6 cases took 9 beats, 3 IHD and 3 controls.

(3 cases were excluded owing to irregularity of heart rate or an abnormal response - cases 1-23, 4-2, and 5-11. One case in the IHD group appears twice - case 5-23).

There was therefore some difference between the groups in the time the heart rate took to return to control, particularly at the shortest and longest times.

Change from Resting Values

At the beat in which the heart rate reached or fell below its control value, the LVETc had reached to within 5 msec. of its control value, or had fallen below it, in 22 out of 31 cases.

Of the other 9 cases, the LVETc reached its resting value at the previous beat in one case, at the next beat in two cases, and a few beats later in 4 cases. (Cases 2-3, 1-21, 3-1, 5-10, 5-29, 3-5 and 2-7). Case 5-23b developed premature beats at this point and then the LVETc fell below control. In two cases the LVETc did not reach its control value at any point. (Cases 4-9 and 5-2). (See also Fig. 11).

At the beat in which the heart rate reached or fell below its resting value, the PEPc was measured in 25 cases and had reached to within 1.9 msec. of its resting value, or had fallen below it, in 24. In the other case the PEPc was 9.4 msec. above its resting value.

In 12 cases the resting PEPc was reached before the heart rate reached its resting value.

In 23 cases the QS2c had reached to within 5 msec. of its resting value, or had fallen below it, and in one case was 7.3 msec. above. In case 5-23b the QS2c was 23.6 msec. above. In 5 cases the QS2c reached the resting value before the heart rate.

Thus, the heart rate, PEPc and LVETc often reached their resting values at different times, but there was a closer relationship between the times of return of the heart rate and of the QS2c. This is illustrated in Fig. 7 for the 15 control subjects and the 6 patients with IHD in Division A. The QS2c and heart rate tended to fall to control at the same time (Fig. 7a). The PEPc tended to fall to control at the same time as the heart rate, or before it (Fig. 7b). The LVETc tended to fall to control at the same time as the heart rate, or later (Fig. 7c).

Even when the falls of heart rate were small, and the heart rate returned closely to its resting value, there was no relationship between the degree of change from the resting values of the heart rate, PEPc, LVETc or QS2c at the returning beat of the heart rate.

(h) The Settled PEPc

The Time the PEPc Settled (Table 13)

In 17 cases the PEPc settled after the returning beat of the heart rate, in 3 cases at the returning beat, and in 4 cases before the returning beat. When the PEPc settled before the returning beat of the heart rate, the time of the returning beat was delayed. (Cases 5-10, 5-26, 5-27 and 5-29). (See also Fig. 10b).

Change from Control

In 4 cases the settled PEPc did not fall below control (Cases 5-6, 5-26, 5-27 and 5-29). In 3 of these the QS2c was above control and the returning beat of the heart rate was delayed, suggesting that one cause of the delay was an inability to increase stroke volume.

In one case (case 5-10) there was a large fall in the PEPc below control but the increase in the LVETc above control was much greater than the fall in the PEPc and the return of heart rate was delayed, suggesting that another cause of the delay was an inability to increase the rate of flow.

On the other hand, in 4 cases the PEPc fell less than 10 msec. below control and the heart rate returned to control 6 to 8 beats after release. (Cases 1-6, 1-21, 2-4 and 3-9). Also, when there were large falls in the PEPc the heart rate returned to control 5 or 6 to 9 beats after release whether or not there were large falls in the LVETc.

In 14 cases the PEPc fell more than 10 msec. below control and the heart rate fell. The fall in heart rate below control was 0 to 11 in 7 cases and 20 to 59 in 7 cases. The average change below control was as follows:-

	PEPc msec.	LVETc msec.	H.R. beats	
7 subjects	-24.2	- 3.5	- 6	
7 subjects	-27.8	-30.4	-31	(Fig. 5)

Thus for a similar average fall in the PEPc below control, the greater the average fall in the LVETc the greater the average fall in the heart rate. This did not apply to individual cases but does suggest that the effect of increase in contractility was not separated from reduction in afterload and both factors may reduce the QS2c.

In some cases shortening of the PEPc may have been due to a fall of blood pressure rather than increase in stroke volume, although

the fall of pressure may have been due to increase in stroke volume. However, when the PEPc did not decrease it may perhaps be assumed that there was no volume overshoot. Cases with no volume overshoot, so estimated, were restricted to the IHD group but there was a volume overshoot of varying degree in all groups. The degree of volume overshoot bore no relation to the control stroke volume (PEPc). In most cases the volume overshoot did not increase after the settled PEPc. (Table 9), and the maximum volume overshoot may have occurred before the settled PEPc.

In one control subject the resting PEPc was large but decreased considerably (case 1-22) so resting values may not reflect the potential response. (Cases 5-11 and 5-18 are not considered here).

Comparison with a Standard (Table 14)

A standard PEPc was derived by obtaining the average resting PEPc of the four athletes (cases 1, 3, 5 and 6 in group 1). This standard of 111.7 msec. was then compared with the values for the PEPc at rest, returning beat of heart rate, settled PEPc and L.S.S. (See also Fig. 10a).

In Table 13 it was found that there were 8 cases where the settled PEPc either did not decrease below control or decreased less than 10 msec., but the heart rate took 10 or more beats to reach control in only 3 of these cases. It is now shown that in 2 of these 3 cases the settled PEPc was much above the standard and in 1 case moderately above. (Cases 5-26, 5-27 and 5-29) i.e. the stroke volume was probably relatively small both at rest and at the settled PEPc, so that

the actual stroke volume attained may be more significant than the overshoot. In case 1-1 the heart rate fell below control 8 beats after the end of strain, the resting PEPc was below the standard, the settled PEPc considerably below and the LVETc at the settled PEPc had fallen over 23 msec. below control i.e. the resting stroke volume was relatively large and there was an overshoot in volume and flow.

On the other hand, when both the resting PEPc and the settled PEPc were relatively large and there was little decrease in the LVETc from control at the settled PEPc (i.e. when the resting stroke volume was relatively small and there was little or no overshoot in volume or flow) the heart rate returned to control 7 and 9 beats after release (cases 1-21 and 3-9).

Therefore another factor may be concerned with the rate of return of heart rate to control other than the actual stroke volume attained and the ability to increase its rate of flow. The rate of increase of stroke volume and rate of flow could not be estimated, and the maximum values may have occurred before the settled PEPc i.e. when the PEPc was most affected by change in pressure.

(i) Rate of Return of H.R., QS2c and LVETc to Control

The heart rate was taken as falling to control when it reached +0.5 beat of the resting value, and the QS2c when it reached +2.4 msec. of the resting value (Table 15). Of the 21 cases in Division A in 16 cases the heart rate and QS2c fell to control in the same beat. In one case the QS2c was 8 msec. above the control value at the beat the heart rate returned to control. In 4 cases the QS2c had fallen below

control in the previous beat by 4.1 to 19.4 msec. but in the case with the greatest fall it had not increased above control. Thus the QS2c and heart rate tended to fall to control at the same time. (See also Fig. 7). The larger falls in heart rate were associated with the larger falls in the QS2c, although the falls were not proportional.

From the end of strain, the LVETc and associated QS2c reached their maximum values at or after the onset of fall of heart rate (Fig. 13a) but, with one exception, the QS2c fell to control either at the same rate as the heart rate or more quickly (Fig. 13b), and the QS2c and heart rate fell from their maxima to control more quickly in the young control subjects than in the patients with IHD.

Also, in the young control subjects the mean maximum increase in the LVETc and QS2c, relative to the heart rate increment, was less than in the patients with IHD and the other groups were intermediate (Fig. 12).

Thus the more rapidly the mean QS2c and heart rate reached control from their maxima the less the rise in the mean LVETc and QS2c (relative to the heart rate increment) before they fell. Therefore, the less the systolic time intervals were affected by resistance to flow the more quickly they returned to control from their maxima i.e. from the time of onset of increase of output over outflow. The rate of increase of output over outflow represents the rate and degree of increase of stroke volume and rate of flow and depends, in this manoeuvre, on left ventricular filling and performance.

The factors concerned with the rate of return of the heart rate to control were therefore taken to be the time required for left ventricular filling and the rate of increase of output over outflow which depends on the actual stroke volume attained in each beat and the ability to increase its rate of flow. It was concluded that the heart rate response alone may be an index of left ventricular performance and the response is examined in Table 16.

In Division B (Table 15) the LVETc did not fall to control with the heart rate, suggesting inability to increase rate of flow, and the heart rate returned to control 10-14 beats from the end of strain in 3 of the 5 cases.

In Division C the rate of return of the systolic time intervals was abnormal or did not correlate with the heart rate.

In case 5-11 the heart rate increment was slight (Table 8) and the heart rate returned to control on the 3rd beat after release and then fell, the PEPc was at the control level on the 2nd beat and the LVETc decreased (Table 6) i.e. stroke volume and rate of flow increased from control but there was little resistance to flow.

Fig. 14 shows that the PEPc increased with a ventricular premature beat in a control record and then decreased with the recovery beat (i.e. the PEPc reflected the decrease and increase of stroke volume) but the LVETc did not rise and fall with the heart rate. In contrast, the LVETc rose and fell with the heart rate after release in case 1-23 in the presence of supraventricular beats and also in case 4-2 when the rate oscillated and the P waves and P-R interval were normal.

In case 5-18 the heart rate increment was 56.4 beats, indicating a considerable increase in sympathetic stimulation. The onset of fall of heart rate was 2 beats after the end of strain but the fall was not sustained and, despite a large fall in one beat, 8 beats were taken from the onset of fall to control. The beat-to-beat fall was irregular. The LVETc was first measured at the 5th beat when the heart rate had already fallen, and was 10.5 msec. above control. At the settled PEPc, the PEPc was 31.1 msec. below control and 33.7 msec. below the standard and the LVETc was 24.3 msec. below control. If this represented a large stroke volume and a large volume and flow overshoot it did not correlate with the heart rate response.

The measurements were checked. The patient had right bundle branch block, inferior wall infarction and a pansystolic apical murmur which had not been regarded as evidence of significant retrograde flow. The control carotid pulse showed a short rapid rate of rise which decreased, there was a small shoulder on the descending limb and a low dicrotic notch i.e. ejection was initially fast and there was no delay in emptying. The onset of the QRS was clear at control and after release. After release, the first heart sound changed its timing and there was a short interval between its onset and the rise of the carotid pulse, but the first heart sound was not used in the measurements. The first component of the second sound varied slightly but corresponded with the dicrotic notch.

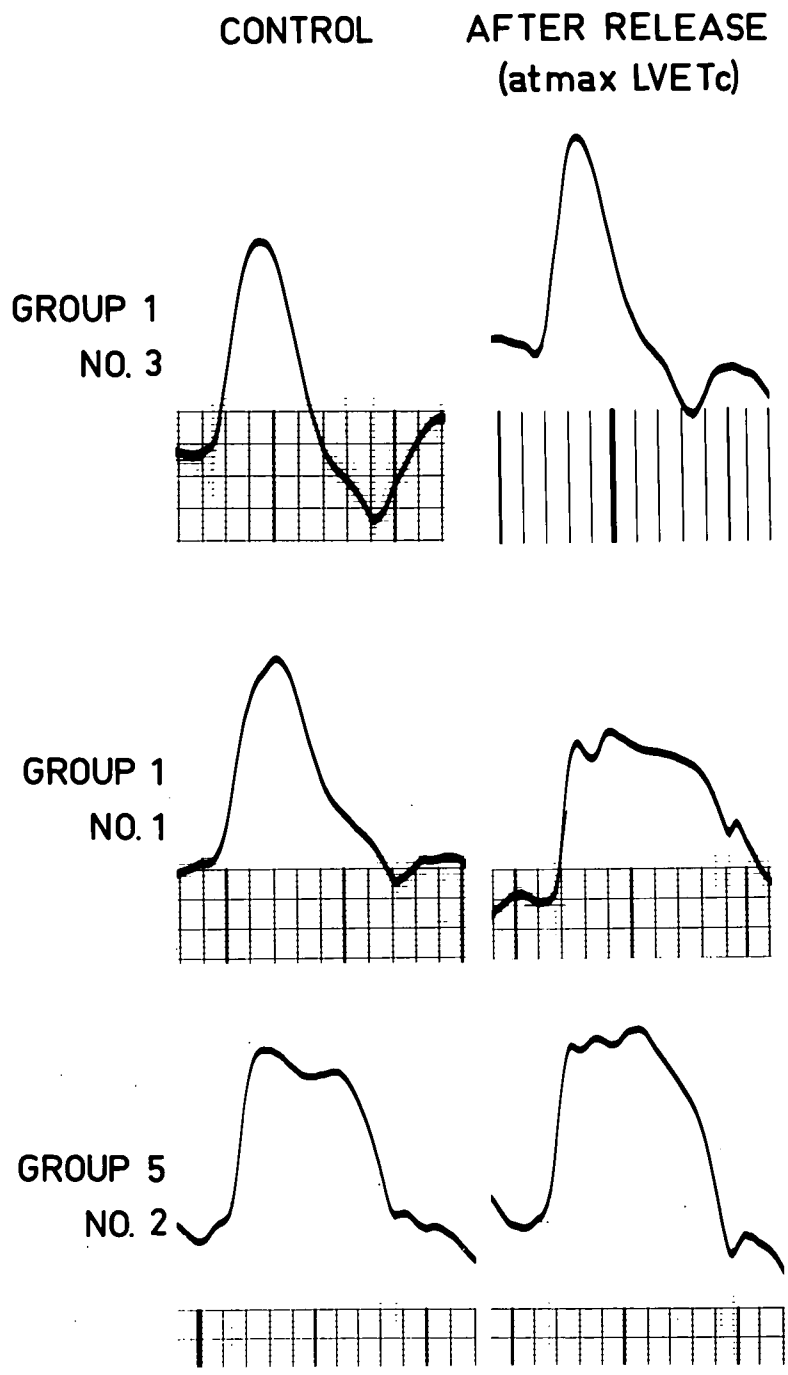


FIG. 15

CAROTID PULSE WAVE FORMS

(Division C)

An alternative explanation for the measurements would be a large end-diastolic volume, which increased, but the effective stroke volume was smaller and delivered rapidly due either to (undetected) regurgitant flow or the development of asynchronicity of contraction.

(j) Carotid Pulse Wave Form and Systolic Time Intervals

The tracings are described as having a high, medium or low shoulder on the descending limb depending on whether the shoulder was above, at, or below half the height of the wave from the onset of the rise to the summit. The control record was compared with the record after release (Fig. 15). As the base line varied, the estimations of change in shoulder height are approximate and the changes in height of the dicrotic notch are not considered.

In the resting records the shoulder was low in all but one case in groups 1 and 2. The shoulder was of medium height in one case of group 2, one case of group 3, and 2 cases of group 5. The shoulder was high in cases 3-9, 4-8, 4-9, 5-2 and 5-10. There was no correlation between shoulder height and the resting systolic time intervals or blood pressure and it may have been related to carotid atherosclerosis or the pressure of the cuff.

After release, the shoulder increased marginally in height in 8 control subjects and in 2 patients with IHD. In the other cases the shoulder increased above control before, at, or just after the maximum LVETc. The increase persisted for 1-4 beats in 10 control

subjects and in 5 patients with IHD. In case 3-5 it was increased for 10 beats, but this was variable. In case 4-2 it was raised for 12 beats while the heart rate oscillated. In the 5 cases where the control shoulder was high it did not increase after release in 2 and the increase varied in 1. In case 4-9 the shoulder was very high before the LVETc attained its maximum and after it decreased but the LVETc did not fall below control. In case 5-10 the shoulder increased and then fell below the control level.

In 3 cases, one beat was double peaked after release (cases 4-8, 4-9 and 5-2). In case 5-26 the control shoulder was low and the peaks after release were bizarre. In case 5-29 the control record was double peaked with the second peak higher than the first. After release, the first peak became higher than the second and later reverted to the control wave form.

Temporary increase in the height of the shoulder after release was attributed to an increase of output over outflow in the carotid segment. The bizarre peaks that occurred after release may have been an artefact or perhaps due to irregular acceleration of the blood column.

HEART RATE RESPONSE ALONE

(a) Rise in Heart Rate during Strain, Persistence after Release and Beat-to-Beat Fall (Table 16a)

The heart rate did not rise or rose slightly during strain in 2 cases (5-8 and 5-13) but both had a bradycardia. In 76 cases the heart rate increment at the onset of fall was adequate, although in 15 of these it had fallen 1-10 beats below the maximum increase in heart rate during strain. In 3 cases the heart rate increment at the onset of fall was 22-25 beats below the maximum heart rate during strain. (Cases 2-2, 5-9 and 5-11).

In four of the young control subjects the heart rate rose and fell after it had reached the resting level. In 3 of the control subjects and in 12 of the patients with IHD the falls to the resting level were irregular and the patients with IHD, as a group, had small falls relative to the heart rate increment.

In 5 cases, where the heart rate increment was adequate, the largest fall in heart rate occurred after the heart rate had reached the resting level, and in case 3-7 this was not associated with a fall in the PEPc. (Cases 3-2, 3-7, 4-9, 5-4 and 5-7).

In 11 control subjects and 5 patients with IHD after the heart rate had reached control there was a further relatively large fall. In one of these, case 5-23a, the PEPc decreased progressively as the heart rate fell from the onset of fall to below control.

(b) Time Intervals (Table 16b)

Examined in 52 control subjects and 24 patients with IHD. In 8 control subjects and 5 patients with IHD the heart rate fell below control 1-2 beats after it had reached it. In cases 5-10 and 5-27, however, it took 3 and 5 beats, and in cases 5-19 and 5-25 it did not reach the average resting level. In the IHD group the heart rate reached control but did not remain there in 9 cases.

The mean values are given in Table 16c. The mean increment in heart rate was greatest in the younger athletic group but similar between the other groups. The time from end of strain to the onset of fall of heart rate increased after 36 years of age but not with further increase in age or in the presence of ischaemic heart disease. The time from the onset of fall of heart rate to control increased after 25 years of age, did not increase further between 26 and 61 years of age in the control subjects, but was greatest in the infarction/ischaemia group in whom the fall in heart rate below control was least. In the infarction/ischaemia group the case with no bradycardia had an increment of 30 beats per minute. The case where the increment was 8 beats per minute had the bradycardia of 41 beats and the control heart rate was 109 beats per minute. The next lowest increment in the group was 16 beats per minute.

Repeatability

9 subjects performed the test twice and 3 subjects three times. In one, the time from onset of fall to control heart rate was 1, 3 and 4 beats. In all the others the time interval either

did not change or varied by one beat.

Time to 40 mmHg.

The time each subject took to blow the pressure up to 40 mmHg. was not standard and may have affected the results. In 4 cases this time was as long as 2.5 to 3.2 seconds. In one young control subject this did not result in a prolongation of the time from onset of fall to control. Two subjects were in the infarction/ischaemia group, the time from onset of fall to control was 6 and 7 beats and the longest time in the group was 8 beats. The fourth subject (case 4-9) had a raised control diastolic pressure and a small pulse pressure, the control carotid pulse wave form was abnormal, and the control PEPc interval was abnormally prolonged so that the time from onset of fall to control of 5 beats was unlikely to be due to the time he took to blow the pressure up to 40 mmHg.

In a small preliminary study the time to reach 40 mmHg. was increased to 3 seconds and appeared to prolong the time from onset of fall to control heart rate in one out of 6 cases, but, in one case, increasing the time to reach 40 mmHg. to 5.5 seconds did not affect the result.

In the course of the investigation it was found that some active people could not reach 40 mmHg. on blowing, others reached and maintained it with difficulty, and some raised the pressure slowly at the start and rapidly at the end.

It may be that the factor which prevents a rapid blow affects the result.

The time to 40 mmHg. was not accurately recorded in cases 2, 24 and 27 group 5 but the increment in heart rate at onset of fall was adequate.

DISCUSSION

The Valsalva Manoeuvre as a Test

The manoeuvre has been of interest to cardiologists for many years but, despite extensive investigations, has had little clinical value as a simple test of left ventricular performance. Interest has been centred on the ability of normal and abnormal hearts to respond to changes in filling pressure by changes in stroke output (Sharpey-Schafer, 1965) and on the bradycardia rather than on the rate of cardiac slowing. But the bradycardia depends on the control heart rate as well as on the rise of blood pressure after release, and the blood pressure rise ("overshoot") is not entirely dependent on left ventricular performance as it is influenced by the degree of arterial vasoconstriction, which is variable. In some cases in this study the heart rate did not increase during strain, or it increased during strain but the increase did not persist after release, but bradycardia occurred.

To be of clinical value, a test of left ventricular performance should indicate or measure how the ventricle responds to changes in filling pressure, sympathetic stimulation and resistance to ejection. Left ventricular power, computed as the product of pressure and rate of change of volume, takes into account the stroke volume, the rate at which it is moved, and resistance to ejection, but this required cardiac catheterisation and biplane angiocardiograms for its evaluation and stress was not employed. (Russell, Porter, Frimer, and Dodge, 1971).

The concept put forward in this Thesis is that the heart rate response to the Valsalva manoeuvre may be used to indicate the left ventricular response to sympathetic stimulation and resistance to ejection as well as to changes in filling pressure. The test depends on the presence of adequate sympathetic stimulation. It may therefore be invalid if the increment is small when the control heart rate is normal but valid if there was sinus tachycardia at rest. The increase in resistance to flow induced by the manoeuvre is used as the stress. Although the resistance to flow is not constant in each case, and the smaller the resistance to flow the less the cardiac effort required for output to increase, yet effort is required for output to increase quickly over the greater outflow. For the same peripheral resistance, or resistance to flow, the sudden ejection of a given mass of blood will result in a greater fall of heart rate - and less increase in the systolic time intervals corrected for heart rate - than a more prolonged ejection. As the corrected systolic time intervals may be increased by the resistance to flow associated with the rise of pressure, whereas the onset of fall of heart rate is quickened by the same rise of pressure, the onset of fall of heart rate is probably as sensitive, or more sensitive, an indicator of the increase of output over outflow. When output begins to exceed outflow the pressure begins to rise, causing the heart rate to slow. The more rapidly output exceeds outflow, and overcomes resistance to ejection, the more rapidly the heart rate returns to control. Assuming that the degree of increase of sympathetic stimulation to the heart is proportional to the degree of

increase in resistance to flow, then the number of beats from the onset of fall of heart rate to control represents the contractile response for the stimulus provided there is no significant regurgitant flow or obstruction to flow. Thus, while the method may not reveal the potential contractile state it may detect differences in the degree of the actual inotropic response.

The Response

Differences were found between the control subjects and the patients with ischaemic heart disease. The more rapidly the heart rate and total systole, corrected for heart rate, fell to control the less the rise in the corrected total systole and ejection periods (relative to the heart rate increment) before they fell to control and the greater the fall in these intervals and heart rate below control. Thus, corrected total systole and heart rate fell to control more rapidly when the left ventricle was more able to increase the rate of flow despite resistance to flow. The patients with ischaemic heart disease were most adversely affected by the increase in resistance to flow induced by the manoeuvre. This may have been due either to their inability to attain an adequate stroke volume or rate of flow, as assessed by the systolic time intervals. Prolongation of the corrected systolic time intervals has been found after exercise in patients with angina (Pouget et al, 1971).

In the heart rate response, an interval of up to 4 beats from the onset of fall to control could be taken as normal from these results. This interval was normal in all of the control subjects aged

16-25 years. Three control subjects, aged 26-46 years, gave abnormal results (5, 6 and 7 beats). Four control subjects, aged 47-61 years, took 5 beats. In the patients with ischaemic heart disease, the interval was 6 or more beats in 17, 5 beats in 3, normal in 4 and in one of these the time from end of strain to onset of fall was prolonged. The results were abnormal in 7 out of 52 control subjects and in 20 out of 24 patients. Another patient (case 5-3) was receiving propranolol and digoxin, the heart rate increment was 40 and the time from onset of fall to control heart rate was 8 beats.

Interpretation

This was not made easier by measuring the time intervals in fractions of a beat rather than in whole beats. In the time from onset of fall to control heart rate there may be a difference of one beat between two records from the same subject and the time interval itself may be only one beat. This may represent sudden filling of the left ventricle rather than better performance.

End of Strain to Onset of Fall of Heart Rate

Delay in filling of the left ventricle may be due to more complete emptying of the lungs as in emphysema or in normal subjects able to force intrathoracic pressure above 60 mmHg. (Mills and Kattus, 1958), an increase in thoracic pressure acting on the left heart and aorta (Sharpey-Schafer, 1965), perhaps to greater left ventricular effort during strain or poor right ventricular performance after release. It was assumed that the time from end of strain till output exceeds outflow

depends on the time required for left ventricular filling as well as on contractility. The increase in this time interval after 36 years may have been mainly due to delay in filling as it did not increase further in the patients with ischaemic heart disease.

Onset of Fall to Control Heart Rate

The heart rate response is dependent on baro-reflex sensitivity and this may be reduced in the elderly (Sharpey-Schafer, 1965) and in hypertension (Bristow et al, 1969) and so the heart rate response may not accurately reflect left ventricular performance. Baroreflex sensitivity was not investigated in this study but it was assumed that the baroreceptors were affected by degree of change of pressure as the heart rate increased during strain and after release. The patients with ischaemic heart disease showed the longest time from onset of fall to control heart rate and the highest resting blood pressures while the youngest group had the shortest time and the lowest blood pressures. But in two of the control subjects where the blood pressure was 154/100 and 160/90 the time from onset of fall to control heart rate was not prolonged (4 and 2 beats). Nevertheless, diminished sensitivity to rate of change of pressure may have been present. The influence of medication could not be excluded as some of the patients were taking diuretics.

Some of the subjects had sinus tachycardia at rest, and were clearly not in a basal state, but the inotropic state was assumed to be relatively constant. No particular time of day was reserved for the test, some subjects interrupting work and some coming after it, some

were apprehensive and this may affect the results. However, the conditions of the test were similar to those encountered in an ordinary consultation.

A normal result represents a normal baroreceptor and cardiac response. An abnormal result might require further evaluation to assess the influence of age, hypertension and respiratory function. It seems likely that abnormal results may be due to impaired left ventricular performance. After infarction, localised areas of the left ventricle may bulge following the Valsalva manoeuvre (Turner and Jacobson, 1969).

Application

Low stroke volumes in patients with heart disease may be detected by measuring the ejection period (Spodick et al, 1969) or the ratio of the pre-ejection period to the ejection period (Weissler et al, 1969). However, a resting value may not reflect the potential response to a stress, as shown in this study, and the Valsalva manoeuvre may be a useful addition to screening procedures.

The heart rate has been employed as a parameter in the response to exercise and training, either alone or in relation to other measurements. (Committee on Exercise and Physical Fitness, 1967; Benestad, 1965; Benestad, 1968; Frick and Katila, 1968; Hamley and Thomas, 1969; Sucec, 1969). Also, when the posture is passively changed from the 20 degree feet down to the horizontal position the heart rate increases if the heart cannot respond by increasing stroke volume (Thomas and Shillingford, 1965), although the ability to increase

stroke volume could not be used as a test of function (Nager, Thomas and Shillingford, 1967). In the normal response, increase in cardiac output is mainly due to an increase in stroke output achieved at the same heart rate or in the presence of a bradycardia. (Thomas and Shillingford, 1965). The change in stroke volume on change of posture was less in healthy old men than in young men (Granath, Jonsson and Strandell, 1964) and the usual lack of response to change of posture in severe heart failure may be altered in the presence of valvular disease. (Lorentsen, Bay, Grendahl and Silvertssen, 1967).

If a patient is able to change stroke volume on change of posture after myocardial infarction, as judged by a test not employing stress, then it may be useful to examine the heart rate response to sympathetic stimulation before embarking on the greater stress of an exercise programme. As the baroreceptor response to the Valsalva manoeuvre would presumably be constant, progress in left ventricular performance in an individual after infarction, or heart failure, and the effect of medication might be assessed by the manoeuvre. Cardiac performance cannot be improved if the potential for improvement has been lost (Anderson, 1969).

Graded physical training may be beneficial in ischaemic heart disease and after infarction (Smith and Kidera, 1967; Kellermann, Levy, Feldman and Hariv, 1967; Lategola and Naughton, 1967), especially if it could be shown that it resulted in an improvement in the inotropic response.

Conclusion

It is suggested that the response to the Valsalva manoeuvre, examined and interpreted in the manner described in this study, may have a useful place in the assessment of overall cardiac performance. The simplicity of the test, and the ease with which results can be obtained, are an advantage over more exact, but more exacting, procedures.

TABLE 1

SYMBOLS

A	-	angina.
C	-	cardiac enlargement. s (slight) m (moderate).
D	-	taking a diuretic.
Em	-	ejection murmur.
Es	-	ejection sound.
Fsp	-	first sound prolonged.
Fss	-	first sound soft.
Hss	-	heart sounds soft.
I	-	the case with ischaemia.
Jvp	-	jugular venous pressure raised.
La	-	liver enlarged, alcohol.
Ll3	-	third sound in left lateral position.
OA	-	obstructive airway disease.
P & Di	-	propranalol and digitalis.
Pam.	-	pansystolic apical murmur.
S	-	systolic time intervals measured.
St	-	systolic thrill.
T	-	tachycardia when excited.

TABLE 1

Group and numbers, age, blood pressure, occupation and significant findings in 81 subjects.

Group 1

(16-25 years)

Number	Age in Years	B.P. mmHg.	Occupation	Comments	
1-1	16	114/58	School		S
1-2	16	122/60	School		
1-3	16	112/76	School		S
1-4	20	122/60	Uni. Student	Es. St.	
1-5	20	114/74	Uni. Student		S
1-6	21	132/88	Uni. Student		S
1-7	$15\frac{1}{2}$	132/68	Nurse		
1-8	16	120/72	Nurse		
1-9	16	124/72	Nurse		
1-10	16	128/80	Nurse		
1-11	16	116/80	Nurse		
1-12	16	124/88	Nurse		
1-13	17	120/70	Nurse		
1-14	17	112/84	Nurse		
1-15	17	122/78	Nurse		
1-16	17	128/80	Nurse		S
1-17	18	117/84	Nurse		
1-18	18	150/74	Nurse	T.	
1-19	20	138/80	Nurse		
1-20	22	140/90	Nurse		
1-21	22	122/80	Nurse		S
1-22	22	140/80	Nurse		S
1-23	25	128/70	Nurse		S
1-24	25	138/78	Nurse		S
1-25	25	140/80	Nurse	Em.	

TABLE 1

Group and numbers, age, blood pressure, occupation and significant findings in 81 subjects.

Group 2

(26-36 years)

Number	Age in Years	B.P. mmHg.	Occupation	Comments	
2-1	26	130/82	Nurse		
2-2	27	160/98	Nursing Aid		
2-3	32	130/76	Nurse		S
2-4	33	130/80	Nurse		S
2-5	34	138/80	Nurse		
2-6	35	124/80	Nurse		
2-7	36	130/92	Nurse		S

Group 3

(37-46 years)

3-1	37	140/72	H.E.C.		S
3-2	37	114/78	Nurse	Em.	
3-3	38	154/100	Nurse		
3-4	40	136/90	Nurse	Fsp.	S
3-5	41	140/74	Nurse	L13., OA.	S
3-6	42	148/90	Nurse		
3-7	43	118/82	Nurse		S
3-8	44	152/96	Nurse		
3-9	46	112/72	Nurse		S

TABLE 1

Group and numbers, age, blood pressure, occupation and significant findings in 81 subjects.

Group 4

(47-61 years)

Number	Age in Years	B.P. mmHg.	Occupation	Comments	
4-1	47	138/82	Nurse		S
4-2	47	150/88	Nurse		S
4-3	47	130/80	Nurse		
4-4	47	120/80	Plumber		
4-5	47	120/80	Electrician		
4-6	49	138/82	Laundry Worker		
4-7	49	140/86	Engineer		
4-8	51	120/78	H.E.C.		S
4-9	57	130/100	Nurse		S
4-10	59	160/90	Nurse		
4-11	61	132/88	Engineer	Cs.	

Group 5

(Infarction/Ischaemia)

5-1	37	138/90	H.E.C.	Hss.	
5-2	42	144/90	Marine Pilot		S
5-3	43	144/80	Warder	A. D. P & Di.	
5-4	44	140/90	Builder	Cm. D. La Pam.	
5-5	44	170/110	Lorry Driver	Cs.	
5-6	46	144/100	Lorry Driver and Loader	A	S
5-7	46	160/100	Warder		
5-8	46	140/90	Mechanic		
5-9	47	130/80	Warder	Pam.	
5-10	48	156/90	Weather Bureau	I.	S
5-11	49	136/94	Bank Manager	Jvp. La.	S
5-12	49	112/90	Clerk	A. D.	

TABLE 1

Group and numbers, age, blood pressure, occupation and significant findings in 81 subjects.

Group 5 (Cont'd)

(Infarction/Ischaemia)

Number	Age in Years	B.P. mmHg.	Occupation	Comments	
5-13	50	130/80	Fitter E.Z.C.	A.	
5-14	50	132/74	Fitter H.E.C.		
5-15	52	130/80	H.E.C.	A. Cm.	
5-16	52	164/102	Seaman		
5-17	53	130/84	Flat Manager	Cs.	
5-18	54	120/74	Cleaner	A. Pam.	
5-19	54	120/80	H.E.C.	Cs.	
5-20	54	144/90	Groundsman		
5-21	55	148/90	Clerk	D.	
5-22	55	132/84	Painter	D. Fss.	
5-23	55	118/78	H.E.C.	D. Hss. Pam.	S
5-24	56	164/88	Foreman/Lab.		S
5-25	56	138/84	Electrician		
5-26	57	138/92	Nurse		S
5-27	59	108/88	Storeman		S
5-28	60	178/94	Public Health		
5-29	61	188/98	Business	A. D.	S

TABLE 2

Mean resting values for the pre-ejection period (PEP), left ventricular ejection time (LVET), total systole (QS2) and PEP/LVET ratio.

Group/No.	PEP m.sec.	LVET m.sec.	QS2 m.sec.	PEP/LVET ratio
1-1	76	298	374	.25
1-3	83	281	364	.29
1-5	81	288	369	.28
1-6	91	287	378	.31
1-16		255		
1-21	99	284	383	.35
1-22	110	267	377	.41
1-23	64	309	373	.21
1-24	99	274	273	.36
2-3	89	286	375	.31
2-4	91	260	351	.35
2-7	95	284	379	.33
3-1	89	234	323	.38
3-4	89	291	380	.30
3-5	88	245	333	.36
3-7	97	268	365	.36
3-9	105	300	405	.35
4-1	102	299	401	.34
4-2	92	304	396	.30
4-8	101	325	426	.31
4-9	126	235	361	.53
5-2	92	292	384	.31
5-6	88	311	399	.28
5-10	108	262	370	.41
5-11	115	289	404	.40
5-18	76	306	382	.24
5-23a	102	265	367	.38
5-23b	122	247	369	.49
5-24	99	234	333	.42
5-26	102	306	408	.33
5-27	119	293	412	.40
5-29	87	310	397	.28

TABLE 3

Mean changes in the left ventricular ejection time (LVET) in msec. during the Valsalva manoeuvre. Comparison of the results of Flessas et al (1970) with the present study.

Phases	Flessas	Present Study			
	22-32 years	16-21 years athletes	22-32 years controls	33-57 years controls	42-61 years IHD
Control	296	288	278	277	284
Strain					
Initial fall	281	247	257	241	
Lowest	226	183	189	181	174
End strain	229	191	194	198	178
Post release					
Fall	220				
Initial rise	284	237	220	238	256
Maximum	306	298	289	302	308
No. of cases	11	4	4	9	8

LVET shortened during strain and increased to a maximum after release.

Cases with abnormality of heart rate or conduction were excluded, as was one control subject, aged 17 years, who was not an athlete. Figures for control, post release rise and maximum taken from 25 cases. There were insufficient figures to show a small initial post release drop. Figures for strain, initial fall, were taken from 10 cases, for lowest from 18 cases and for end strain, 16 cases.

TABLE 4a

Average resting values of heart rate and systolic time intervals, corrected for heart rate.

Group/No.	Heart Rate/min.	LVETc (m.sec.)	PEPc (m.sec.)	QS2c (m.sec.)
1-1	74.1	427.8	105	532.8
1-3	79	410.4	114.1	524.5
1-5	80.5	423.4	113.4	536.8
1-6	58.8	386.7	114.4	501.1
1-16	88.4	405.3		
1-21	79.2	420.3	130.2	550.5
1-22	85.4	412.5	143.5	556
1-23	60.8	412.1	88.2	500.3
1-24	75.4	402.6	129.8	532.4
2-3	71.1	400.3	115.8	516.1
2-4	89.5	412.4	126.3	538.7
2-7	87.2	423.7	138.4	562.1
3-1	103.7	414.2	130.1	544.3
3-4	74.8	418.2	121.4	539.6
3-5	98.2	411.6	128.9	540.5
3-7	105.1	444.4	138.8	583.2
3-9	70.8	420	133.6	553.6
4-1	71.5	420.5	130.4	550.9
4-2	81.7	442.5	125.2	567.7
4-8	57.5	422.3	122.6	544.9
4-9	91.9	389.9	163.1	553
5-2	70.5	403.9	127.4	531.3
5-6	63.4	419.5	116.2	535.7
5-10	91.7	418	144.4	562.4
5-11	75.8	415.9	145	560.9
5-18	71.6	428.5	109.1	537.6
5-23a	88.4	414.6	137.5	552.1
5-23b	87.5	396.9	157.3	556.2
5-24	97	399.6	143.1	542.7
5-26	69.4	424.4	146.9	571.3
5-27	56.7	390	141.7	531.7
5-29	84.2	453.6	122.2	575.8

TABLE 4b

Range of resting values of heart rate and systolic time intervals, corrected for heart rate.

Group/No.	Heart Rate/min.	LVETc (m.sec.)	PEPc (m.sec.)
1-1	66.5- 84	415 -444.9	90.4-121.6
1-3	70.5- 90.5	396.4-424.1	105.2-123.8
1-5	72.5- 89	408.8-438.5	97 -131.2
1-6	55.5- 63	377 -403.3	96.2-126.2
1-16	82 - 95.5	394.8-415.3	
1-21	77 - 81.5	406.8-427.6	122.8-139
1-22	78.5- 92	393.4-428.5	133.8-156.8
1-23	55.5- 67	398.6-421.9	75.8-107.2
1-24	70.5- 84	392.8-419.8	121 -136.6
2-3	60.5- 80	378.8-414.1	103 -122.2
2-4	85 - 93	401.9-427.2	119 -134.8
2-7	83.5- 90.5	417 -433.2	128.5-149.7
3-1	101 -106	409.5-418.5	121.4-142.2
3-4	70.5- 80.5	402.8-425.8	112.2-134.2
3-5	94 -102	389.3-433.4	121.2-137.2
3-7	101 -108	437.8-452.2	132.2-147.4
3-9	68 - 73	406.8-429.8	130.2-140.6
4-1	67 - 75	402.1-426.7	120.4-139.8
4-2	79.5- 84	434.4-449	115 -130.6
4-8	56 - 58.5	410.6-430.2	114.4-131.2
4-9	90.5- 95	382.8-398.2	153.2-170.6
5-2	69 - 72	395.1-415.4	120 -136.8
5-6	62.5- 64.5	408.8-427.5	112 -119.2
5-10	89.5-100	404.2-435.5	136.4-152.2
5-11	73.5- 77.5	398.9-430.9	131.6-157.8
5-18	65 - 81	418.5-439.7	100.4-126
5-23a	82.5- 91	406.5-423.8	131.2-144.2
5-23b	83.5- 90.5	380.3-407.2	133.6-190.8
5-24	95.5-100	388.6-418	140.2-146.2
5-26	67 - 70.5	413.8-435	137 -158.4
5-27	54 - 60.5	374.1-402.2	130.6-150.2
5-29	82 - 86	433.1-465.6	107 -134.4

TABLE 4c

Systolic time intervals, resting values, from Weissler et al (1968).

Patient	H.R. bts/min.	QS2 msec.	QS2c msec.	LVETc msec.	PEPc msec.
R.B.	75	388	545.5	373.5	172
S.H.	110	327	558	343	215
F.B.	76	386	545.6	382.2	163
R.K.	70	395	542	393	149
J.P.	83	366	540.3	347.1	166
T.P.	97	362	565.7	402.9	153
W.W.	84	333	509.4	362.8	147
H.M.	84	337	513.4	348.8	165
P.W.	95	390	589.5	380.5	209
A.A.	68	409	551.8	383.6	168
E.C.	107	326	550.7	372.9	178
O.H.	80	404	572	362	210
J.H.	91	355	546.1	353.7	192
M.S.	95	355	554.5	354.5	200
R.B.	87	346	528.7	371.9	157
O.B.	72	373	524.2	344.4	180
E.K.	86	377	557.6	387.2	170
H.B.	81	396	566.1	376.7	190
N.S.	80	381	549	371	178

TABLE 5

The change in the left ventricular ejection time corrected for heart rate (LVETc) during strain.

Group/No	Early Stfain m.sec.	Mid Strain m.sec.	Late Strain m.sec.
1-1	- 63.2	- 74.5	- 61.3
1-3	- 2.4	- 37.1	- 40.4
1-5	- 17.3	- 12.4	- 51.2
1-6			- 19
1-16	- 40.2	- 26.2	- 50.7
1-21	- 54.2	- 51.9	- 60.4
1-22	- 37.4	- 35.6	- 23.6
1-23		- 37	- 34.3
1-24		- 14.9	- 13.5
2-7	- 70.9	- 60.9	- 39.9
3-1	- 54.7	- 33.9	- 18
3-4	- 20	- 48.1	- 37.4
3-7	- 90.9		- 69.7
3-9	- 45.4	- 42.3	- 55.2
4-1		- 63.2	- 68.9
4-2	- 65.6		
4-8	- 32.7		- 47.1
5-6	- 70.9	-109.3	
5-11	- 76.8		
5-23b	- 85.2	- 71	
5-29	- 84.9	-109.1	-101

The LVETc decreased during strain.

TABLE 6

Heart Rate, LVETc and PEPc after release.

Division A

Beat	Case 1-1 Heart Rate in bt/min.	LVETc in msec.	PEPc in msec.	Case 1-3 Heart Rate in bt/min.	LVETc in msec.	PEPc in msec.
1	126			95		
2	128			99		
3	129			100.5	429.8	94.2
4	131			97	426.9	106.8
5	138	465.6		69	383.3	105.6
6	128	460.6	141.2	75	415.5	84
7	75	422.5	100	70.5	417.8	87.2
8	63	404.1	90.2	68.5		
9	54	383.8	93.6	65.5		
10	48	331.6	104.2	76.5	417	95.6
11	46.5	357	100.6	70.5	403.8	76.2
12	45.5	364.3	96.2	66.5	407	82.6
13	45.5	332.3	95.3	62	405.4	84.8
14	46.5			57.5	391.7	84
15	46			57.5		
16	46			60.5	380.8	94.2
17	46.5			65	395	100.5
18	45.5			58	400.8	82
19	45.5			54		

TABLE 6

Heart Rate, LVETc and PEPc after release.

Division A

Beat	Case 1-5			Case 1-6		
	Heart Rate in bt/min.	LVETc in msec.	PEPc in msec.	Heart Rate in bt/min.	LVETc in msec.	PEPc in msec.
1	161			86		
2	127			83.5	382.9	144.4
3	106	398.2	114.4	80.5		
4	116	455.2	118.4	82	404	126.8
5	100	447	113	68.5	394.4	123.4
6	47.5	365.7	77	57.5	381.7	109
7	63	387.1	100.2	73	391.1	140.2
8	54	379.8	83.6	57	392.9	110.8
9	51	376.9	80.2	51	382.7	104.4
10	50	362	85	53.5	380.9	116.4
11	53	367.1	85.2	47.5	366.7	114
12	53.5	386.9	90.4	53.5	378.9	116.4
13	46	369.2	82.4	55	376	121.5
14	46	367.6	82	52		
15	46	364.6	91	51		
16	48			54		
17	50.5			51	380.8	113.3
18	50			46.5		
19	51			53.5		

TABLE 6

Heart Rate, LVETc and PEPc after release.

Division A

Beat	Case 1-21 Heart Rate in bt/min.	Case 1-21 LVETc in msec.	Case 1-21 PEPc in msec.	Case 1-22 Heart Rate in bt/min.	Case 1-22 LVETc in msec.	Case 1-22 PEPc in msec.
1	90	360		128		
2	95	388.5	155	129	396.3	
3	98	414.6	140.2	131	409.7	150.4
4	100.5	431.8	142.2	131	434.7	140.4
5	100	443	140	129	451.3	136.6
6	94	434.8	142.6	117	456.9	132.8
7	77.5	429.9	121	62.5	376.2	97
8	66.5	413	126.6	61.5	350.5	121.6
9	60.5	404.8	125.2	56	334.2	123.4
10	57.5	404.7	124	51	321.9	145.2
11	57	407.9	121.8	55	333.5	122
12	58	383.7	130	62	370,4	113.8
13	58	381.8	136	49.5	346.1	117.8
14	58			50.5	363.8	113.2
15	58.2			52	356.2	118
16	59.5			57	368.2	110.5
17	62.5			54		
18	65			52		
19	63			50.5		

TABLE 6

Division A

Beat	Case 1-24			Case 2-3		
	Heart Rate in bt/min.	LVETc in msec.	PEPc in msec.	Heart Rate in bt/min.	LVETc in msec.	PEPc in msec.
1	86	342.2	140.4	116		
2	92.5	373.2	134	118.5	385.4	
3	100	411	120	123		
4	105	423.5	134	120		
5	106	440.2	124.4	115	445.4	131
6	115	445.5	145	96	430.2	120.4
7	51	343.9	99.2	74	394.8	116.6
8	75	397.5	110	70.5	405.8	95.2
9	72.5	395.2	111	60	398	87
10	64	380.8	103.6	58.5	394.4	91.4
11	54	356.8	99.6	59.5	366.2	105.7
12	58.5	369.4	103.4	67		
13	57	361.2	95.5	64.5		
14	68	378.8	112	58.5	397.2	
15	61.5			58		
16	59.5			65	377.8	96
17	68			73.5		
18	56			61.5		
19	64.5			58.5	383.6	95.2

TABLE 6

Heart Rate, LVETc and PEPc after release.

Division A.

	Case 2-4			Case 2-7		
Beat	Heart Rate in bt/min.	LVETc in msec.	PEPc in msec.	Heart Rate in bt/min.	LVETc in msec.	PEPc in msec.
1	126			96		
2	120			101		
3	120			101	307.6	268.5
4	120	409	147	100.5	446.8	137.2
5	112	430.4	130.8	100	454	134
6	84	392.8	125.6	96	459.6	126
7	81.5	411.5	116.6	92	461.2	125
8	75.5	398.3	118.2	88	450.8	123
9	61.5	369.5	116.6	81	444.6	110.5
10	64	380.8	116.6	75.5	442.8	105.7
11	63	377.1	117.2	71	431.6	109.5
12	62.5	371.2	111	70.5	426.8	112.2
13	65	370.5	121	70.5		
14	66			69.5	419.2	130.7
15	65			69	422.4	129.5
16	66.5			66.5	422.4	
17	68			65	419	126.5
18	70			65.5	420.8	119.7
19	70			68.5		

TABLE 6

Heart Rate, LVETc and PEPc after release.

Division A

Beat	Case 3-4			Case 3-7		
	Heart Rate in bt/min.	LVETc in msec.	PEPc in msec.	Heart Rate in bt/min.	LVETc in msec.	PEPc in msec.
1	97			140		
2	99			142		
3	103	373.1	131.2	142		
4	100	402	128	145		
5	89.5	417.1	104.8	142	462.4	136.8
6	82.5	418.2	102	145	477.5	153
7	74.5	408.6	103.8	128	480.6	132.2
8	72	413.4	95.8	117	478.9	118.8
9	71	409.7	105.4	89	444.3	106.6
10	67	399.9		45.5	317.3	105.2
11	66.5	403	96.6	142	363.4	175.8
12	64.5	393.6	104.8	44.5	350.6	90.8
13	65	385	109.5	38	329.6	104.2
14	65.5			47.5	367.7	
15	66	385.6	112	45	363.5	107
16	65.5			48		
17	60			45.5	365.8	103.7
18	62.5			50.5		
19	65			48		

TABLE 6

Heart Rate, LVETc and PEPc after release.

Division A

Beat	Case 3-9			Case 4-1		
	Heart Rate in bt/min.	LVETc in msec.	PEPc in msec.	Heart Rate in bt/min.	LVETc in msec.	PEPc in msec.
1	98			112		
2	100.5			115		
3	103	393.1		117		
4	103	420.1	148.2	117		
5	104	445.8	152.6	118.5	467.4	132.4
6	98	447.6	142.2	118.5	471.4	139.4
7	89	444.3	152.6	116	473.2	147.4
8	70	421	134	93	446.1	139.2
9	66.5			50.5	406.8	108.2
10	70	419	133	58	412.6	112.2
11	71			59	405.3	109.6
12	75.5	435.3	134.2	57.5	399.7	120
13	66	424.2	125.4	55	397.5	114
14	55.5	409.4	117.1	54.5	390.6	117.8
15	56.5	396	124.6	54		
16	60.5	401.8	130.2	54		
17	59.5	411.2	130.7	55.5		
18	57			55.5	388.8	124.7
19	57			54.5	395.2	115.2

TABLE 6

Heart Rate, LVETc and PEPc after release.

Division A

Beat	Case 4-8			Case 5-6		
	Heart Rate in bt/min.	LVETc in msec.	PEPc in msec.	Heart Rate in bt/min.	LVETc in msec.	PEPc in msec.
1	97			94		
2	100			96		
3	100.5			99		
4	100.5			98		
5	100	444	144	91	463.7	134.4
6	94	469.8	114.6	74.5		
7	84	450.8	119.6	66	424.2	117.4
8	61.5	429.5	105.6	59	407.3	125.6
9	54	419.8	104.6	56	402.2	121.4
10	53	414.1	117.2	53.5	397.6	123.7
11	51	418.9	96.2	55.5		
12	49.5	407.1	98.8	54		
13	48			55	407.5	117
14	48.5	408.4	101.4	54.5	416.6	100.8
15	48.5	406.6	99.3	55.5	393.8	112.7
16	49	397.4	100.5	57		
17	47.5			58		
18	47			62		
19	46.5	407.4	102.3	62	400.2	113

TABLE 6

Heart Rate, LVETc and PEPc after release.

Division A

Beat	Case 5-10			Case 5-23a		
	Heart Rate in bt/min.	LVETc in msec.	PEPc in msec.	Heart Rate in bt/min.	LVETc in msec.	PEPc in msec.
1	136			112		
2	136			104		
3	137			112		
4	138			111		
5	136			111		
6	131			110	417	168
7	127			97	+412.9	155.8
8	129	472.3	137.6	70.5	+381.8	138.2
9	118.5	483.4	112.4	55	379.5	114
10	108	455.6	125.2	57	373.9	
11	93	443.1	115.2	54		
12	88.5	440.4	99.4	57	372.9	128.8
13	82	422.4	117.8	58	369.6	
14	94			58.5	375.4	137.4
15	63.5	391.9	105.4	57	375.9	
16	64	387.8	109.6	56.5	376	
17	62	378.4	116.8	58	365.8	144
18	61	368.6	122.5	58.5	379.6	132.2
19	62.5			59.5		

+ = not less than

TABLE 6

Heart Rate, LVETc and PEPc after release.

Division A

Beat	Case 5-26			Case 5-27		
	Heart Rate in bt/min.	LVETc in msec.	PEPc in msec.	Heart Rate in bt/min.	LVETc in msec.	PEPc in msec.
1	94			76.5		
2	93			75.5		
3	94			76		
4	95			77	393.9	164.8
5	97			73.5	406.9	153.4
6	100			70.5	408.8	152.2
7	98	446.6	167.2	65	399.5	155
8	100	464	168	58.5	396.4	145.4
9	94	453.8		57.5	391.7	148
10	89.5			57	393.9	142.8
11	82.5	425.2	159	57		
12	80.5	448.8	147.2	57.5	379.7	151
13	72.5			57.5	393.7	126
14	70.5	432.6	152.4	58		
15	67	424.8	148.8	55		
16	65	418.5	140	54.5	383.2	129.2
17	65	416.5	150	54.5	391.2	130.2
18	66.5	425	147.5	56	383.6	137
19	66.5			57		

TABLE 6

Heart Rate, LVETc and PEPc after release.

Division A

Case 5-29

Beat	Heart Rate in bt/min.	LVETc in msec.	PEPc in msec.	Beat	Heart Rate in bt/min.	LVETc in msec.	PEPc in msec.
1	99	386.2	172.5	20	76	433.6	118
2	101	399.7	172.4	21	76.5	424.4	126.2
3	102	401.8	162	22	80	428	130
4	103	445.1	154.9	23	82.5	445	122.2
5	104	467.8	136.6	24	85	434	120.5
6	103	482.1	133.2	25			
7	104	477.8	125.6	26			
8	100	470	132	27			
9	102	491.4	130.8	28			
10	96	486.2	125.4	29	92	449.1	116.8
11	95	489.5	123	30	92	434.3	120.6
12	92.5	490.2	122				
13	90.5	473.8	129.2				
14	89	482.3	134.6				
15	86	467.6	120				
16	81	467.7	115.4				
17	77.5	458.7	110				
18	75.5	433.3	125.2				
19	74.5	437.2	118.2				

TABLE 6

Heart Rate, LVETc and PEPc after release.

Division B

Beat	Case 1-16			Case 3-1		
	Heart Rate in bt/min.	LVETc in msec.	PEPc in msec.	Heart Rate in bt/min.	LVETc in msec.	PEPc in msec.
1	125			137		
2	125			140		
3	121.5	401.5		138		
4	117	418.9		138	444.6	
5	107	422.9		134.5	456.6	
6	64.5	346.6		124	462.8	
7	69	381.3		102	445.4	
8	70	379		94	427.8	115.6
9	68.5	372.4		82	412.4	112.8
10	70.5	377.8		70.5	396.8	96.2
11	67.5	364.7		66.5	373	110.6
12	70	374		70	370	114
13	74.5	373.6		79	393.2	119.7
14	84	397.8		59	361.3	105.6
15	74			89		
16	79.5	400.1		77.5		
17	79.5			62		
18	79.5			68		
19	57			72		

TABLE 6

Heart Rate, LVETc and PEPc after release.

Division B

Beat	Case 3-5			Case 4-9		
	Heart Rate in bt/min.	LVETc in msec.	PEPc in msec.	Heart Rate in bt/min.	LVETc in msec.	PEPc in msec.
1	125			114		
2	126			113		
3	125			113		
4	126	398.2		113		
5	126			114		
6	127			113	399.1	
7	124			112	430.4	
8	123			111		
9	118.5	467.4		106	449.2	
10	110	438		92.5	452.2	
11	109	462.3		69.5	420.1	
12	101	440.7		63	407.1	
13	92.5	433.2		63	404.1	
14	87	417.9		60	401	
15	76.5	389		58	393.6	
16	76.5	381		58.5	395.4	
17	79	394.3		61.5		
18	78.5	394.6		64.5		
19	76.5			67		

TABLE 6

Heart Rate, LVETc and PEPc after release.

Division B

Beat	Case 5-2			Case 5-24		
	Heart Rate in bt/min.	LVETc in msec.	PEPc in msec.	Heart Rate in bt/min.	LVETc in msec.	PEPc in msec.
1	97			127		
2	95.5			127		
3	100			125		
4	101	438.7	138.4	127		
5	100	446	145	131	407.7	
6	93			131	437.7	
7	87	459.9	121.8	129		
8	78	456.6		124	460.8	
9	57.5	429.7		124	460.8	
10	57.5			112		
11	53.5	431.9		105	401.5	
12	51.5	419.5		95.5	419.3	
13	52.5	422		100.5	431.8	
14	51.5	413.4		97		
15	53			93	427.1	
16	52.5			89.5	427.1	
17	52.5			82		
18	52.5			73	406.1	
19	54			70.5	373.8	
20						
21						
22						
23				65	384.5	
24				66	397.2	

TABLE 6

Heart Rate, LVETc and PEPc after release.

Division B

Case 5-23b

Beat	Heart Rate in bt/min.	LVETc in msec.	PEPc in msec.
1	105		
2	105		
3	109		
4	107	402.9	
5	108	419.6	178.2
6	109		
7	106	432.2	167.4
8	100.5	431.8	
9	88	422.6	155.2
10	116	365.2	202.4
11	51	385.9	93.2
12	89	407.3	171.6
13	64	385.8	130.6
14	63.5	376.9	144.4
15	62.5	385.2	137
16	62.2	372.2	148
17	63		
18	66		
19	69		

TABLE 6

Heart Rate, LVETc and PEPc after release.

Division C

Beat	Case 1-23			Case 5-11		
	Heart Rate in bt/min.	LVETc in msec.	PEPc in msec.	Heart Rate in bt/min.	LVETc in msec.	PEPc in msec.
1	117			81		
2	121.5			80	388	146
3	120	419	135	77.5	385.7	149
4	120	447		73.5	396.9	134.4
5	98	434.6		70	395	133
6	96	452.2		68	404.6	117.2
7	75	422.5	106	67	391.9	128.8
8	95	432.5		70	409	124
9	37.5	355.7	89	73		
10	81.5	430.5		79.5	418.1	135.8
11	51.5	382.5		80	434	133
12	52	385.4		78		
13	50	377	98	72	417.4	133.8
14	39	376.3		68		
15	39			70		
16	41			75		
17	40.5			71.5		
18	42.5			74		
19	42			75.5		

TABLE 6

Heart Rate, LVETc and PEPc after release.

Division C

Case 5-18

Beat	Heart Rate in bt/min.	LVETc in msec.	PEPc in msec.
1	121.5		
2	128		
3	124		
4	117		
5	89.5	426.1	102.8
6	90	439	77
7	76.5	416	89.6
8	76.5	413	87.6
9	72.5	404.2	78
10	71.5	391.5	
11	75.5	412.3	
12	69	399.3	
13	63.5	379.9	
14	62	377.4	84.8
15	59	384.3	69.6
16	54.5	364.6	69.8
17	54	377.8	60.6
18	53	365.1	62.2
19	48		

TABLE 6

Heart Rate, LVETc and PEPc after release.

Division C

Case 4-2

Beat	Heart Rate in bt/min.	LVETc in msec.	PEPc in msec.	Beat	Heart Rate in bt/min.	LVETc in msec.	PEPc in msec
1	142			20	100	457	113
2	142			21	83	429.1	103.2
3	136			22	102	455.4	118.8
4	129	430.3		23	84	425.8	
5	118.5	439.4		24	98	451.6	116.2
6	100	420		25	76.5	407	111.6
7	94	429.8		26	52	358.4	94.8
8	91	428.7	112.4	27	56.5	374	94.6
9	91	441.7	104.4	28	59.5	380.1	101.8
10	99	456.3	122.6	29	66.5	383	111.6
11	102	454.4	116.8				
12	117	468.9	129.8				
13	89.5	433.1	116.8				
14	108	466.6					
15	91	437.7					
16	107	466.9					
17	83	428.1	103.2				
18	100	451	122				
19	79	416.3	99.6				

TABLE 7

Degree of decrease in the PEPc after release, from the beat where it was first measured to the beat where its value was lowest, and the phase of heart rate where the PEPc attained its lowest value.

(Phases of heart rate:- one - at the maximum fall of heart rate in one beat; two - after it; three - later, but before the lowest settled state of the heart rate; four - at the lowest settled state H.R.).

Group/No.	Fall PEPc m.sec.	Phase H.R.	Group/No.	Fall PEPc m.sec.	Phase H.R.
1-5	37.4	one	1-23	37	four
1-21	34	one	1-24	44.9	four
1-22	53.4	one	2-4	36	four
4-1	24.2	one	3-7	33.1	four
1-1	51	two	3-9	31.1	four
5-11	28.8	two	4-2	17.8	four
5-23a	54	two	5-6	33.6	four
1-3	18	three	5-18	42.2	four
1-6	40	three	5-23b	41.2	four
2-3	44	three	5-26	27.2	four
2-7	31.5	three	5-27	38.8	four
3-1	19.4	three	5-29	18.6	four
3-4	35.4	three			
4-8	47.8	three			
5-10	38.2	three			

The PEPc decreased after release. The lowest value of the PEPc was not related to any particular phase of the heart rate.

TABLE 8

The relation between the increase in heart rate from control during strain and after release and between the increase in the LVETc and QS2c from control.

	Change from Control HEART RATE (bt/min)				LVETc (msec) / QS2c (msec)	
	During Strain		After Release		After Release	
	Max.	End	At Onset Sustained fall H.R.	At Max. LVETc	At Max. LVETc	At Max. QS2c
Division A						
Group/No.						
1-1	+50.9	+41.9	+63.9	+63.9	+37.8	+69
1-3	+21	+21	+21	+21.5	+19.4	+ 9.2
1-5	+38	+35.5	+35.5	+35.3	+31.8	+37.4
1-6	+22.7	+22.7	+23.2	+23.2	+15.3	+29.7
1-21	+13.2	+ 7.8	+21.3	+20.8	+22.7	+32.5
1-22	+43.6	+43.6	+45.6	+31.6	+44.4	+33.7
1-24	+39.6	+16.1	+39.6	+39.6	+42.9	+58.1
2-3	+39.9	+39.9	+51.9	+43.9	+45.1	+60.3
2-4	+34.5	+33.5	+30.5	+22.5	+18	+22.5
2-7	+14.8	+ 7.8	+13.3	+ 4.8	+37.5	+25.9
3-4	+38.2	+29.2	+28.2	+ 7.7	0	- 9.6
3-7	+32.9	+32.9	+39.9	+22.9	+36.2	+47.3
3-9	+25.2	+25.2	+33.2	+27.2	+27.6	+44.8
4-1	+40.5	+40.5	+47	+44.5	+52.7	+69.7
4-8	+38	+38	+43	+36.5	+47.5	+43.1
5-6	+29.1	+28.1	+35.6	+27.6	+44.2	+62.4
5-10	+48.3	+44.3	+46.3	+26.8	+65.4	+47.5
5-23a	+15.6	+15.6	+23.6	+21.6	+ 2.4	+32.9
5-26	+23.6	+23.6	+30.6	+30.6	+39.6	+60.7
5-27	+20.8	+20.8	+20.3	+13.8	+18.8	+29.3
5-29	+16.8	+15.8	+17.8	+17.8	+37.8	+46.4

TABLE 8

The relation between the increase in heart rate from control during strain and after release and between the increase in the LVETc and QS2c from control.

	Change from Control HEART RATE (bt/min)				LVETc (msec) / QS2c (msec)	
	During Strain		After Release		After Release	
	Max.	End	At Onset Sustained fall H.R.	At Max. LVETc	At Max. LVETc	At Max. QS2c
Division B.						
Group/No.						
1-16	+40.6	+38.6	+36.6	+18.6	+17.6	
3-1	+34.3	+34.3	+34.3	+20.3	+48.6	
3-5	+26.8	+25.8	+28.8	+20.3	+55.8	
4-9	+21.1	+21.1	+22.1	+ 0.6	+62.3	
5-2	+26.5	+26.5	+30.5	+16.5	+56	
5-24	+31	+28	+34	+27	+61.2	
5-23b	+28.5	+10.5	+21.5	+18.5	+35.3	+45.4
Division C.						
Group/No.						
1-23	+55.2	+55.2	+59.2	+35.2	+40.1	
4-2	+61.8	+61.8	+60.3	+35.3	+26.4	+31
5-11	+30.2	+ 4.2	+ 5.2	- 7.8	-11.3	-26.2
5-18	+53.4	+53.4	+56.4	+18.4	+10.5	- 8.7

TABLE 9

The degree of change after release from the maximum values to the values at the lowest settled state of the heart rate (L.S.S.); and the change from control values at the L.S.S. The maximum value for the heart rate is taken at the onset of the sustained fall of heart rate and the maximum values for the LVETc and QS2c are taken at the maximum measured values. The maximum PEPc could not be measured as it occurs too early. Where the PEPc was smaller at the settled PEPc than at the L.S.S. this is noted. Results taken in order of degree of fall of heart rate.

	Degree of Change to L.S.S.		
Group/No.	H.R. bt/min.	LVETc msec.	QS2c msec.
3-7	- 101.8	- 128.3	- 176.8
1-1	- 91.7	- 119.3	- 156.7
4-2	- 83.4	- 95.1	- 124.4
1-22	- 79.2	- 98.4	- 116.4
5-10	- 75.4	- 101.8	- 114.8
1-23	- 73.4	- 71.9	
5-18	- 72.9	- 66.1	- 91.5
3-1	- 69.4	- 88.6	
1-5	- 68.2	- 83.2	- 115.8
4-1	- 63.7	- 80.2	- 109.7
2-3	- 62.7	- 64.9	- 98.9
5-24	- 62.4	- 70.4	
2-4	- 56.4	- 55.5	- 69.9
1-24	- 55.7	- 79	- 121.4
1-16	- 54.4	- 50.4	
4-9	- 54.2	- 53.7	
5-23a	- 54	- 42.8	- 76
4-8	- 51.9	- 64.9	- 82.3
3-5	- 49.4	- 77.7	
5-2	- 48.8	- 73.6	
3-9	- 46	- 43	- 68.2
5-23b	- 45.9	- 52.2	- 77.8
5-6	- 44.4	- 61.1	- 82
1-21	- 42.4	- 48.5	- 56.6
1-3	- 39.8	- 37.8	- 51.6
3-4	- 37.5	- 26.4	- 32.5
5-26	- 34.2	- 42.8	- 64.3
2-7	- 33.8	- 40.9	- 41.1
1-6	- 29.7	- 26.4	- 38.2
5-29	- 26	- 59.6	- 69.7
5-27	- 21.4	- 20.9	- 42.5
5-11	- 5.7	+ 15	+ 16.5

TABLE 9

Change from Control at L.S.S. and Settled PEPc.

Group/No.	H.R. bt/min.	LVETc msec.	QS2c msec.	PEPc msec.	PEPc msec.
3-7	-61.9	-92.1	-129.5	-37.4	
1-1	-27.8	-81.5	- 87.5	- 6	-14.8
4-2	-23.1	-68.7	- 93.2	-24.5	
1-22	-33.6	-54	- 82.7	-28.7	
5-10	-29.1	-36.4	- 67.3	-30.9	-32
1-23	-12.7	-31.8	- 22	+ 9.8	
5-18	-16.5	-55.6	-100.2	-44.6	
3-1	-35.1	-40	- 58.7	-18.7	-33.9
1-5	-32.7	-51.4	- 78.4	-27	-33.2
4-1	-16.7	-27.5	- 40	-12.5	-22.2
2-3	-10.8	-19.8	- 38.6	-18.8	-28.8
5-24	-29	- 9.2			
2-4	-25.9	-37.5	- 47.4	- 9.9	
1-24	-16.1	-36.1	- 63.3	-27.2	
1-16	-17.8	-32.8			
4-9	-32.1	+ 8.6			
5-23a	-30.4	-26.8	- 47.2	-20.4	-23.5
4-8	- 9.4	-17.4	- 39.2	-21.8	
3-5	-20.6	-21.9			
5-2	-18.3	+17.6			
3-9	-12.8	-15.4	- 23.4	- 8	
5-23b	-24.4	-34.6	- 32.1	+ 2.5	
5-6	- 8.8	-16.9	- 19.6	- 2.7	
1-21	-21.6	-25.8	- 28.1	- 2.3	- 3.6
1-3	-18.8	-18.4	- 42.4	-24	-30.1
3-4	- 9.3	-26.4	- 42.1	-15.7	-25.6
5-26	- 3.6	- 3.2	- 3.6	- .4	
2-7	-20	- 3.4	- 15.2	-11.8	-32.7
1-6	- 6.5	-11.1	- 8.5	+ 2.6	- 5.4
5-29	- 6.2	-21.8	- 23.3	- 1.5	
5-27	- 1.1	- 2.1	- 13.2	-11.1	
5-11	- 0.5	+ 3.7	- 9.7	-13.4	

TABLE 10

The relation of the change of the PEPc to the maximum fall of heart rate in one beat during the sustained fall of heart rate; and the relation of the S1-AO interval to the PEPc. Taken in order of maximum fall of heart rate in one beat. Beat number 5 is the return beat H.R. i.e. the beat in which the heart rate reaches or passes the control value. Heart rate in beats per minute. PEPc and S1-AO in m.seconds.

		Beat to Beat Change of H.R., PEPc and S1-AO					
Group/No.		1.	2.	3.	4.	5.	6.
1-24	H.R.	+ 7.5	+ 5	+ 1	+ 9	-64	+24
	PEPc	120	134	124.4	145	99.2	110
	S1-AO	18	24	25	47	21	24
1-22	H.R.	+2	0	- 2	-12	-54.5	- 1
	PEPc	150.4	140.4	136.6	132.8	97	121.6
	S1-AO	23	28	30	29	22	20
1-1	H.R.	+ 1	+ 2	+ 7	-10	-53	-12
	PEPc				141.2	100	90.2
	S1-AO				37	25	20
1-5	H.R.	-34	-21	+10	-16	-52.5	+15.5
	PEPc		114.4	118.4	113	77	100.2
	S1-AO		22	20	23	18	25
3-7	H.R.	- 3	+ 3	-17	-11	-28	-43.5
	PEPc	136.8	153	132.2	118.8	106.6	105.2
	S1-AO	44	47	23	34	20	12
4-1	H.R.	+ 1.5	0	- 2.5	-23	-42.5	+ 7.5
	PEPc	132.4	139.4	147.4	139.2	108.2	112.2
	S1-AO	25	22	35	46	30	29
1-3	H.R.	- 5	+ 4	+ 1.5	- 3.5	-28	+ 6
	PEPc			94.2	106.8	105.6	84
	S1-AO			4	16	27	7
2-4	H.R.	- 6	0	0	- 8	-28	- 2.5
	PEPc			147	130.8	125.6	116.6
	S1-AO			31	19	24	24
5-18	H.R.	+ 0.5	-13.5	0	- 4	- 1	+ 4
	PEPc	77*	89.6	87.6	78		
	S1-AO	14	1	7	12		
5-23a	H.R.	- 1	0	- 1	-13	-26.5	-15.5
	PEPc			168	155.8	138.2	114
	S1-AO			58	53	39	28
4-8	H.R.	- 0.5	- 6	-10	-22.5	- 7.5	- 1
	PEPc	144	114.6	119.6	105.6	104.6	117.2
	S1-AO	41	22	37	35	45	43

* PEPc maximum beat was 102.8 and H.R. was 27

TABLE 10

The relation of the change of the PEPc to the maximum fall of heart rate in one beat during the sustained fall of heart rate; and the relation of the S1-AO interval to the PEPc.

		Beat to Beat Change of H.R., PEPc and S1-AO					
Group/No.		1.	2.	3.	4.	5.	6.
2-3	H.R.	- 3	- 5	-19	-22	- 3.5	-10.5
	PEPc		131	120.4	116.6	95.2	87
	S1-AO		18	17	16		8
3-9	H.R.	0	+ 1	- 6	- 9	-19	- 3.5
	PEPc	148.2	152.6	142.2	152.6	134	
	S1-AO	27	44	43	52	37	
1-21	H.R.	+ 3	+ 2.5	- 0.5	- 6	-16.5	-11
	PEPc	140.2	142.2	140	142.6	121	126.6
	S1-AO	29	35	27	40	32	40
5-6	H.R.	- 1	- 7	-16.5	- 8.5	- 7	- 3
	PEPc		134.4		117.4	125.6	121.4
	S1-AO		55				
5-10	H.R.	+ 2	-10.5	-10.5	-15	- 4.5	- 6.5
	PEPc	137.6	112.4	125.2	115.2	99.4	117.8
	S1-AO	33	21	33	36	18	30
1-6	H.R.	- 2.5	- 3	+ 1.5	-13.5	-11	+15.5
	PEPc	144.4		126.8	123.4	109	140.2
	S1-AO	53		46	48	51	53
5-23b	H.R.	+ 1	+ 1	- 3	- 5	-12	
	PEPc	178.2		167.4		155.2	
	S1-AO	59		58		65	
5-29	H.R.	- 3	- 2	- 1	- 3	- 5	- 4
	PEPc	122	129.2	134.6	120	115.4	110
	S1-AO	29	38	34	32	35	32
3-4	H.R.	+ 4	- 3	-11	- 7	- 8	- 2
	PEPc	131.2	128	104.8	102	103.8	95.8
	S1-AO	47	33	33	31	26	27
2-7	H.R.	0	- 4	- 4	- 4	- 7	- 6
	PEPc	134	126	125	123	110.5	105.7
	S1-AO	33	25	23	30	24	26
5-26	H.R.	- 7	- 2	- 8	- 2	- 3	- 2
	PEPc	159	147.2		152.4	148.8	140
	S1-AO		38		41	32	39
5-27	H.R.	- 3	- 5	- 7	- 1	0	0
	PEPc	152.2	155	145.4	148	142.8	
	S1-AO	70	76	75	81	73	
5-11	H.R.		+ 1	- 1	- 3	- 4	- 3
	PEPc			146	149.	134.4	133
	S1-AO			49	48	36	42

TABLE 11

The change in the PEPc, and other indices, before and between two relatively settled states of the PEPc i.e. the beat after the return beat of heart rate where the PEPc 'settles' and ceases to decrease and the first beat of the lowest settled state (L.S.S.) of the heart rate, (heart rate taken to nearest whole beat).

Change from Return Beat H.R. to Settled PEPc.

Group/No.	No. of Beats	H.R. bt/min.	PEPc msec.	LVETc msec.	QS2c msec.
1-1	1	- 12	- 9.8	- 18.4	- 28.2
1-3	1	+ 6	- 21.6	+ 32.2	+ 10.6
1-5	3	+ 4	+ 3.2	+ 11.2	+ 14.4
1-6	3	+ 6	- 4.6	+ 1	- 3.6
1-21	1	- 11	+ 5.6	- 16.9	- 11.3
1-22	1	- 1	+ 24.6	- 25.7	- 1.1
1-24	1	+ 24	+ 10.8	+ 53.6	+ 64.4
2-3	1	- 10	- 8.2	- 7.8	- 16
2-4	1	- 3	- 9	+ 18.7	+ 9.7
2-7	1	- 6	- 4.8	- 1.8	- 6.6
3-1	3	- 32		- 48.6	
3-4	1	- 2	- 8	+ 4.8	- 3.2
3-7	1	- 44	- 1.4	-127	-128.4
3-9	2	0	- 1	- 2	- 3
4-1	0	0	0	0	
4-8	0	0	0	0	
5-6	1	- 3	- 4.2	- 5.1	- 9.3
5-18	0	0	0	0	
5-23a	1	- 15	- 24.2	- 2.3'	- 26.5'
5-23b	4	- 24	- 24.6	- 36.8	- 61.4

' = not less than.

TABLE 11

Change from Settled PEPc to L.S.S.

Group/No.	No. of Beats	H.R. bt/min.	PEPc msec.	LVETc msec.	QS2c msec.
1-1	2	- 15	+ 14	- 72.5	- 58.5
1-3	8	- 18	0	- 23.8	- 23.8
1-5	3	+ 2	+ 10.2	+ 10	+ 20.2
1-6	1	+ 2	+ 12	- 1.8	+ 10.2
1-21	2	- 9	- 2.6	- 8.3	- 10.9
1-22	5	- 12	- 3.8	- 4.4	- 8.2
1-24	3	- 21	- 10.4	- 40.7	- 51.1
2-3	1	- 2	+ 4.4	- 3.6	+ 0.8
2-4	3	- 17	0	- 30.7	- 30.7
2-7	4	- 6	+ 25	- 23.6	+ 1.4
3-1	1	- 4	+ 14.4	- 23.8	- 9.4
3-4	3	- 6	+ 0.8	- 10.4	- 9.6
3-7	2	- 1	- 14.4	+ 33.3	+ 18.9
3-9	4	- 15	- 15.9	- 9.6	- 25.5
4-1	4	+ 5	+ 5.8	- 9.3	- 3.5
4-8	5	- 6	- 3.2	- 11.4	- 14.6
5-6	1	- 3	+ 2.3	- 4.6	- 2.3
5-18	6	- 13	- 8.4	- 19.9	- 28.3
5-23a	3	+ 2	+ 14.8	- 6.6	+ 8.2
5-23b	0	0	0	0	0

TABLE 11

In the following 5 cases the PEPc settled before the heart rate reached the control level.

Group/No.	No. of Beats	H.R. bt/min.	PEPc msec.	LVETc msec.	QS2c msec.
Change from Settled PEPc to Return Beat H.R.					
4-2	3	- 26	- 7.2	- 48.4	- 55.6
5-10	3	- 30	- 13	- 43	- 56
5-26	3	- 13	+ 1.6	- 24	- 22.4
5-27	2	- 1	- 2.6	- 2.5	- 5.1
5-29	6	- 15	- 10	- 18.5	- 28.5
Change from Return Beat H.R. to L.S.S.					
4-2	1	- 24	- 16.8	- 48.6	- 65.4
5-10	3	- 25	+ 6	- 48.5	- 42.5
5-26	0	0	0	0	0
5-27	3	0	- 16.8	- 0.2	- 17
5-29	2	- 7	+ 2.8	- 30.5	- 27.7
Change from Settled PEPc to L.S.S.					
4-2	4	- 50	- 24	- 97	-121
5-10	6	- 55	- 7	- 91.5	- 98.5
5-26	3	- 13	+ 1.6	- 24	- 22.4
5-27	5	- 1	- 19.4	- 2.7	- 22.1
5-29	8	- 22	- 7.2	- 49	- 56.2

TABLE 12

Time of return to, and change from, resting values.
Shows the number of beats from end of strain (E.S.) to the beat in which each index reaches or passes its control value; and the change from the control value of each index at the beat in which the heart rate reaches or passes its control value. Cases in which the heart rate returns most closely to its control value on the return beat; and in which the falls of heart rate per beat are small, are taken first.

	Number of Beats from E.S. to Control Value				At Returning Beat H.R. Change from Control			
Group/ No.	H.R. No.	LVETc No.	PEPc No.	QS2c No.	H.R. bt/min.	LVETc msec.	PEPc msec.	QS2c msec.
5-24	14	19			-0.2	+27.5		
5-27	10	9	13	12	+0.3	+ 3.9	+ 1.1	+ 5
3-4	7	6	5	4	-0.3	- 9.6	-17.6	-27.2
2-3	8	7	8	7	-0.6	+ 5.5	-20.6	-15.1
4-9	10	∅			+0.6	+62.3		
3-9	8	8	8	8	-0.8	+ 1	+ 0.4	+ 1.4
5-18	10	7	5	5	-0.1	-37		*
					+0.9	-24.3	-31.1	-55.4
5-23b	9	13	9	13	-0.5	+25.7	- 2.1	+23.6
1-6	6	6	6	6	-1.3	- 5	- 5.4	-10.4
1-21	7	8	7	8	-1.7	+ 9.6	- 9.2	+ 0.2
3-1	7	9	8'	8'	-1.7	+31.2		
5-11	4		4		-2.3	-19	-10.6	-29.6
5-26	15	16	12	16	-2.4	+ 0.4	+ 1.9	+ 2.3
5-10	12	15'	8'	11	-3.2	+22.4	-45	-22.6
5-29	16	18'	12	17'	-3.2	+14.1	- 6.8	+ 7.3
4-8	9	9	6	8	-3.5	- 2.5	-18	-20.5
5-6	8	8	14'	8	-4.4	-12.2	+ 9.4	- 2.8
4-2	25	4	8'	8'	-5.2	-35.5	-13.6	-49.1
2-4	6	6	6	6	-5.5	-19.6	- 0.7	-20.3
3-5	13	15			-5.7	+21.6		
2-7	9	14'	4	9	-6.2	+20.9	-27.9	- 7

∅ = LVETc did not return to control

' = or earlier

* = previous beat

TABLE 12

Group/ No.	Number of Beats from E.S. to Control Value: H.R. No.	LVETc No.	PEPc No.	QS2c No.	At Returning Beat H.R. Change from Control: H.R. bt/min.	LVETc msec.	PEPc msec.	QS2c msec.
1-23	11	11			- 9.3	-29.6		
1-3	5	5	3'	3'	-10	-27.1	- 8.5	-35.6
5-2	9	Ø	7'		-13	+25.8		
5-23a	8	7	9	8	-17.5	-32.8	+ 0.7	-32.1
1-1	7	7	7	7	+ 0.5	- 5.3	- 5	-10.3
3-7	9	9	5	9	-16.1	- 0.1	-32.2	-32.3
4-1	9	9	9	9	-21	-13.7	-22.2	-35.9
1-22	7	7	4	7	-22.9	-36.3	-46.5	-81.8
1-16	6	6			-23.5	-58.7		
1-24	7	7	3	7	-24.4	-58.7	-30.6	-89.3
1-5	6	6	5	6	-33	-57.7	-36.4	-94.1

Ø = LVETc did not return to control

' = or earlier

* = previous beat

TABLE 13

The Settled PEPc.

Group/No.	Control PEPc m.sec.	Settled PEPc m.sec.	Settled PEPc bt.no.	Return Beat H.R.
1-1	105	90.2	8	7
1-3	114.1	84	6	5
1-5	113.4	80.2	9	6
1-6	114.4	104.4	9	6
1-21	130.2	126.6	8	7
1-22	143.5	121.6	8	7
1-24	129.8	110	8	7
2-3	115.8	87	9	8
2-4	126.3	116.6	7	6
2-7	138.4	105.7	10	9
3-1	130.1	96.2	10	7
3-4	121.4	95.8	8	7
3-7	138.8	105.2	10	9
3-9	133.6	133	10	8
4-1	130.4	108.2	9	9
4-8	122.6	104.6	9	9
5-6	116.2	121.4	9	8
5-10	144.4	112.4	9	12
5-11	145	117.2	6	4
5-18	109.1	78	9	9
5-23a	137.5	114	9	8
5-23b	157.3	130.6	13	9
5-26	146.9	147.2	12	15
5-27	141.7	145.4	8	10
5-29	122.2	125.4	10	16

Cases 1-23 and 4-2 excluded owing to arrythmia. Case 5-23b developed premature beats between the returning beat and the settled PEPc.

TABLE 13

The Settled PEPc.

Group/No.	Change from Control at Settled PEPc. PEPc. msec.	LVETc. msec.	QS2c msec.	H.R. bt/min.
1-1	-14.8	-23.7	-38.5	-11
1-3	-30.1	+ 5.1	-25	- 4
1-5	-33.2	-46.5	-79.7	-29
1-6	- 5.4	- 5	-10.4	- 1
1-21	- 3.6	- 7.3	-10.9	-12
1-22	-21.9	-62	-82.9	-23
1-24	-19.8	- 5.1	-24.9	0
2-3	-28.8	- 2.3	-31.1	-11
2-4	- 9.7	- 0.9	-10.6	- 7
2-7	-32.7	+19.1	-13.6	-11
3-1	-33.9	-17.4	-51.3	-33
3-4	-25.6	- 4.8	-30.4	- 3
3-7	-33.6	-27.1	-60.7	-59
3-9	- 0.6	- 1	- 1.6	- 1
4-1	-22.2	-13.7	-35.9	-20
4-8	-18	- 2.5	-20.5	- 3
5-6	+ 5.2	-17.3	-12.1	- 7
5-10	-32	+65.4	+33.4	+26
5-11	-27.8	-11.3	-39.1	- 8
5-18	-31.1	-24.3	-55.4	0
5-23a	-23.5	-35.1	-58.6	-33
5-23b	-26.7	-11.1	-37.8	-23
5-26	+ 0.3	+24.4	+24.7	+11
5-27	+ 3.7	+ 6.4	+10.1	+ 1
5-29	+ 3.2	+32.6	+35.8	+12

TABLE 14

Comparison with Group I, No's. 1, 3, 5, and 6, average control PEPc (111.7 msec.).

	At Control PEPc.	At the Beat where the H.R. fell below control		At Settled PEPc.		At L.S.S. PEPc.
			bt.no.	bt.no.		
Division A.						
Group/No.						
1-1	- 6.7	-21.5	8	8	-21.5	-12.7
1-3	+ 2.4	- 6.1	5	6	-27.7	-21.6
1-5	+ 1.7	-34.7	6	9	-31.5	-25.3
1-6	+ 2.7	- 2.7	6	9	- 7.3	+ 5.3
1-21	+18.5	+ 9.3	7	8	+14.9	+16.2
1-22	+31.8	-14.7	7	8	+ 9.9	+ 3.1
1-24	+18.1	-12.5	7	8	- 1.7	- 9.1
2-3	+ 4.1	-16.5	8	9	-24.7	-14.7
2-4	+14.6	+13.9	6	7	+ 4.9	+ 4.9
2-7	+26.7	- 1.2	9	10	- 6	+14.9
3-4	+ 9.7	- 7.9	7	8	-15.9	- 6
3-7	+27.1	- 5.1	9	10	- 6.5	-10.3
3-9	+21.9	+22.3	8	10	+21.3	+13.9
4-1	+18.7	- 3.5	9	9	- 3.5	+ 6.2
4-8	+10.9	- 7.1	9	9	- 7.1	-10.9
5-6	+ 4.5	+13.9	8	9	+ 9.7	+ 1.8
5-10	+32.7	-12.3	12	9	+ 0.7	+ 1.8
5-23a	+25.8	+26.5	8	9	+ 2.3	+23.9
5-26	+35.2	+37.1	15'	12	+35.5	+34.8
5-27	+30		15	8	+33.7	+18.9
5-29	+10.5	+ 3.7	16	10	+13.7	+ 9
Division B.						
3-1	+18.4		7	10	-15.5	- 0.3
5-23b	+45.6	+18.9	13'	13		+28.3
Division C.						
4-2	+13.5	- 0.1	25	25	- 0.1	-11
5-11	+33.3	+22.7	4	6	+ 5.5	+19.9
5-18	- 2.6		12	9	-33.7	-47.2

' = first beat of L.S.S.

TABLE 15

Change from control, before and after heart rate returns to control. Heart rate in bt/min.; LVETc and QS2c in msec.

Group/ No.	CHR.	Previous Beats 1.	Previous Beats 2.	Return Beat H.R.	Following Beats 1.	Following Beats 2.
1-1	74 H.R.	+64	+54	+ 1	-11	-20
	LVETc	+36.8	+32.8	- 5.3	-23.7	-44
	QS2c		+69	-10.3	-38.5	-55.4
1-3	79 H.R.	+21.5	+18	-10	- 4	- 8.5
	LVETc	+19.4	+16.5	-27.1	+ 5.1	+ 7.4
	QS2c	- 0.5	+ 9.2	-35.6	-25	-19.5
1-5	80 H.R.	+36	+20	-32.5	-17	-26
	LVETc	+31.8	+23.6	-57.7	-36.3	-43.6
	QS2c	+36.8	+23.2	-94.1	-49.5	-73.4
1-6	59 H.R.	+23	+ 9.5	- 1.5	+14	- 2
	LVETc	+17.3	+ 7.7	- 5	+ 4.4	+ 6.2
	QS2c	+29.7	+16.7	-10.4	+30.2	+ 2.6
1-16	88 H.R.	+29	+19	-23.5	-19	-18
	LVETc	+13.6	+17.6	-58.7	-24	-26.3
	QS2c					
1-21	79 H.R.	+21	+15	- 1.5	-12.5	-18.5
	LVETc	+22.7	+14.5	+ 9.6	- 7.3	-15.5
	QS2c	+32.5	+26.9	+ 0.2	-10.9	-20.5
1-22	85 H.R.	+44	+32	-22.5	-23.5	-29
	LVETc	+38.8	+44.4	-36.3	-62	-78.3
	QS2c	+32.9	+34.7	-81.8	-82.9	-97.4
1-23	61 H.R.	+14	+34	-23.5	+21.5	- 9.5
	LVETc	+10.4	+20.4	-56.4	+18.4	-29.6
	QS2c	+28.2		-55.6		
1-24	75 H.R.	+31	+40	-24	0	- 2.5
	LVETc	+37.6	+42.9	-58.7	- 5.1	- 7.4
	QS2c	+32.2	+58.1	-89.3	-24.9	-26.2
2-3	71 H.R.	+25	+ 3	- 0.5	-11	-12.5
	LVETc	+29.9	- 5.5	+ 5.5	- 2.3	- 5.9
	QS2c	+34.5	- 4.7	-15.1	-31.1	-30.3

TABLE 15

Change from control, before and after heart rate returns to control. Heart rate in bt/min.; LVETc and QS2c in msec.

Group/ No.	CHR.	Previous Beats 1.	Previous Beats 2.	Return Beat H.R.	Following Beats 1.	Following Beats 2.
2-4	89 H.R.	+31	+23	- 5	-13.5	- 7.5
	LVETc	- 3.4	+18	-19.6	-14.1	- 0.9
	QS2c	+17.3	+22.5	-20.3	-22.2	-10.6
2-7	87 H.R.	+ 5	+ 1	- 6	-11.5	-16
	LVETc	+37.5	+27.1	+20.9	+19.1	+ 7.9
	QS2c	+24.1	+11.7	- 7	-13.6	-21
3-1	104 H.R.	+30.5	+20	- 2	-10	-22
	LVETc	+42.4	+48.6	+31.2	+13.6	- 1.8
	QS2c				- 0.9	-19.1
3-4	75 H.R.	+14.5	+ 7.5	- 0.5	- 3	- 4
	LVETc	- 1.1	0	- 9.6	- 4.8	- 8.5
	QS2c	-17.7	-19.4	-27.2	-30.4	-24.5
3-5	98 H.R.	+11	+ 3	- 5.5	-11	-21.5
	LVETc	+50.7	+29.1	+21.6	+ 6.3	-22.6
	QS2c					
3-7	105 H.R.	+23	+12	-16	-59.5	+37
	LVETc	+36.2	+34.5	- 0.1	-27.1	-81
	QS2c	+29.6	+14.5	-32.3	-160.7	-44
3-9	71 H.R.	+27	+18	- 1	- 4.5	- 1
	LVETc	+27.6	+24.3	+ 1		- 1
	QS2c	+36.2	+43.3	+ 1.4		- 1.6
4-1	71 H.R.	+45	+22	-20.5	-13	-12
	LVETc	+52.7	+25.6	-13.7	- 7.9	-15.2
	QS2c	+69.7	+34.4	-35.9	-26.1	-36
4-8	57 H.R.	+27	+ 4.5	- 3	- 4	- 6
	LVETc	+28.5	+ 7.2	- 2.5	- 8.2	- 3.4
	QS2c	+25.5	- 9.8	-20.5	-13.6	-29.8
4-9	92 H.R.	+19	+14	+ 0.5	-22.5	-29
	LVETc		+59.3	+62.3	+30.2	+17.2
	QS2c					

TABLE 15

Change from control, before and after heart rate returns to control. Heart rate in bt/min.; LVETc and QS2c in msec.

Group/ No.	CHR.	Previous Beats 1.	Previous Beats 2.	Return Beat H.R.	Following Beats 1.	Following Beats 2.
5-2	70 H.R.	+17	+ 8	-12.5	-12.5	-16.5
	LVETc	+56	+52.7	+25.8		+28
	QS2c	+50.4				
5-6	63 H.R.	+11.5	+ 3	- 4	- 7	- 9.5
	LVETc		+ 4.7	-12.2	-17.3	-21.9
	QS2c		+ 5.9	- 2.8	-12.1	-14.4
5-10	92 H.R.	+16	+ 1	- 3.5	-10	+ 2
	LVETc	+37.6	+25.1	+22.4	+ 4.4	
	QS2c	+18.4	- 4.1	-22.6	-22.2	
5-11	76 H.R.	+ 4	+ 1.5	- 2.5	- 6	- 8
	LVETc	-27.9	-30.2	-19	-20.9	-11.3
	QS2c	-26.9	-26.2	-29.6	-32.9	-39.1
5-18	72 H.R.	+ 4.5	+ 4.5	+ 0.5	- 0.5	+ 3.5
	LVETc	-12.5	-15.5	-24.3	-37	-16.2
	QS2c	-32	-37	-55.4		
5-23a	88 H.R.	+22	+ 9	-17.5	-33	-31
	LVETc	+ 2.4	- 1.7	-32.8	-35.1	-40.7
	QS2c	+32.9	+16.4	-32.1	-58.6	
5-23b	87 H.R.		+ 2	-23	-23.5	-24.5
	LVETc		+10.4	-11.1	-20	-11.7
	QS2c		+24.7	-39.8	-34.9	-34
5-24	87 H.R.	+ 6	+ 2.5	- 5	-14	-16.5
	LVETc	+27.5	+27.5		+ 6.5	-25.8
	QS2c					
5-26	69 H.R.	+ 3.5	+ 1.5	- 2	- 4	- 4
	LVETc		+ 8.2	+ 0.4	- 5.9	- 7.9
	QS2c		+13.7	+ 2.4	-12.8	- 4.8
5-27	57 H.R.	+ 8	+ 1.5	+ 0.5	0	0
	LVETc	+ 9.5	+ 6.4	+ 1.7	+ 3.9	
	QS2c	+22.8	+10.1	+ 8	+ 5	
5-29	84 H.R.	+ 5	+ 2	- 3	- 6.5	-10.5
	LVETc	+28.7	+14	+14.1	+ 5.1	-20.3
	QS2c	+41.1	+11.8	+ 7.3	- 7.1	-17.3

TABLE 16a

Control heart rate (CHR). The degree of the rise in heart rate from control at the maximum heart rate during strain (M.S.) and at the onset of the sustained fall of heart rate after release (O.F.) in beats per minute.

The relation of the beat to beat fall in heart rate from the onset of sustained fall (O.F.) to the returning beat (CHR) to the rise in heart rate from control. The change in heart rate of the beat following the return of heart rate to control is shown in brackets. Cases in which the fall in heart rate is not sustained are shown separately. Table arranged according to group and number.

Group/ No.	CHR.	Rise M.S.	H.R. O.F.	Beat to Beat Fall H.R. from O.F. to CHR.	E.S. to L.S.S.	Change from CHR. at L.S.S.
1-1	74	51	64	10,53(12)	10	-28
1-2	79	42	46	10,60(0)	10	-34
1-3	79	21	21	3,28(+6)	14	-19
1-4	51	29	32	6,17,9(1)	13	- 5
1-5	80	38	35	16,52,(+16)	12	-33
1-6	59	23	23	13,11(+16)	10	- 7
1-7	111	31	23	14,35(20)	16	-52
1-8	68	8	24	2,35(+19,+4,-35)	7	-15
1-9	92	28	33	2,14,59(+9)	9	-37
1-10	89	22	36	76,(+44,-19,+39,-68,+13,-4)	12	-34
1-11	87	40	46	62(25,+16,-13)	14	-39
1-12	70	31	37	4,20,29(+13,-9,-9)	11	-22
1-13	84	41	43	7,24,38(10)	8	-36
1-14	71	65	57	36,14,32(+5)	8	-26
1-15	53	50	56	4,10,+8,4,34,23,(0)	7	- 7
1-16	88	41	37	3,5,10,42(+5)	10	-18
1-17	74	19	41	11,32(+2)	10	-14
1-18	133	31	25	3,32(25)	18	-67
1-19	92	35	41	4,12,24(17)	13	-28
1-20	103	39	42	3,4,9,33(30)	7	-35
1-21	79	13	21	6,16(12)	10	-22
1-22	85	44	46	2,13,54(1)	13	-33
1-23	65	48	50	15,38(2)	11	-13
1-24	75	40	40	64(+24)	11	-16
1-25	91	51	45	13,41(7)	9	-32
2-1	75	36	34	4,5,10,20(9)	8	-19
2-2	92	35	13	9,6(33)	7	-28
2-3	71	40	52	3,5,19,22,4(10)	10	-11
2-4	89	34	30	8,28(3)	10	-26
2-5	64	28	32	4,11,10,4,1,3(3)	11	- 7
2-6	77	23	32	6,22,4(19)	7	-17

TABLE 16a

Group/ No.	CHR.	Rise M.S.	H.R. O.F.	Beat to Beat Fall H.R. from O.F. to CHR.	E.S. to L.S.S.	Change from CHR. at L.S.S.
2-7	87	15	14	(1.0,0)4,4,7(6)	14	-20
3-1	104	34	34	4,10,22(8)	11	-35
3-2	95	30	34	4,10,19(25)	10	-32
3-3	75	7	14	6,6,6(+2,-6,-4)	8	-10
3-4	75	38	28	3,10,7,8(3)	11	- 9
3-5	98	27	29	3,1,4,9,1,8,8(6)	15	-21
3-6	95	38	30	18,44(34 dropped beat)	12	-44
3-7	105	33	40	17,11,28(43)	12	-62
3-8	92	18	23	6,3,10,12(6)	10	-15
3-9	71	25	33	6,9,19(4)	14	-13
4-1	71	40	47	3,23,42(+8)	13	-17
4-2a	82	62	60	not sustained	26	-23
4-2b	87	50	43	4,0,0,18,27(3)	15	-24
4-3	101	22	24	5,13,10(55 dropped beat)	16	-42
4-4	71	14	25	5,8,3,9(6)	11	- 9
4-5	74	26	35	4,13,20(13)	14	-22
4-6	90	30	35	5,11,8,6,14(5,1,6)	13	-28
4-7	98	19	25	12,22(9)	16	-51
4-8	57	38	43	1,6,10,22(8)	14	- 9
4-9	92	21	23	1,1,1,5,14(23)	13	-32
4-10	71	25	26	5,7,8,8(4)	9	- 6
4-11	76	31	31	2,7,4,22(+1)	15	-15
5-1	76	35	40	6,3,11,6,10,7(4)	13	-15
5-2	70	26	30	1,7,6,9,20(0)	11	-18
5-3	55	36	40	2,0,4,11,11,7,+5,11(9)	14	- 2
5-4	89	14	16	4,0,6,6(7,11)	11	-14
5-5	60	29	32	2,2,6,9,7,4,3(2,1)	14	- 3
5-6	63	29	36	1,7,17,8,7(3)	10	- 9
5-7	77	26	30	2,4,5,7,7,8(25)	not attained	
5-8	81	-3	1	1,5,5,0(2)	12	-14
5-9	81	32	9	15(15)	9	-20
5-10	92	48	46	2,5,4,+2,10,11,15,4(7)	15	-29
5-11	76	30	5	1,2,4(4)	8	- 1
5-12	109	6	8	4,+1,+1,8,20(18)	12	-41
5-13	59	1	2	4(2,1)	10	- 6
5-14	63	30	38	5,11,12,+11,10,1,11(4)	23	- 8
5-15	78	22	25	7,15,7(4)	15	-12
5-16	69	38	40	2,2,0,2,0,7,18,17(4,+1,+2)	12	-10
5-17	76	39	41	2,4,4,20,2,18(9)	12	-18
5-18	72	53	56	4,7,27,1,14,0,4,1,(+4)	15	-16
5-19	73	17	18	1,6,1,7(2)	14	+ 4
5-20	71	12	25	3,1,2,10,0,5,2,2(+2)	17	- 3

TABLE 16a

Group/ No.	CHR.	Rise M.S.	H.R. O.F.	Beat to Beat Fall H.R. from O.F. to CHR.	E.S. to L.S.S.	Change from CHR. at L.S.S.
5-21	82	18	38	9,4,7,5,4,2,20(+2)	11	-14
5-22	68	15	24	1,6,5,7,6(1)	13	- 6
5-23a	88	16	22	1,13,27(15)	12	-30
5-23b	87	28	21	not sustained	13	-24
5-24	97	31	34	2,5,0,12,7,10,+5,3,(4)	18	-29
5-25	58	17	25	3,4,5,5,3(2)	9	+ 4
5-26	69	24	31	6,5,7,2,8,2,3(3)	15	- 4
5-27	57	20	20	3,3,5,7,1,1(0)	13	- 1
5-28	70	15	25	2,1,3,5,6,13(2)	15	- 7
5-29	84	17	18	4,+2,6,1,3,2,1,3,5(4)	19	- 6
1-23				+1,+4,-2,0,-22,-2,-21,+20, -57,+44,-30		
4-2a				-1,0,-6,-7,-11,-18,-6,-3,0, +8,+3,+15,-27,+28,-17,+16, -24,+17,-21,+21,-17,+19,-18, +14,-21		
5-23b				+16,0,+4,-2,+1,+1,-3,-6,-12, +28,-65,+38,-25		

TABLE 16b

Time from end of strain (E.S.) till the heart rate reaches or passes the control level on the returning beat (CHR). Time from end of strain (E.S.) till the heart rate falls below the control level by one or more beats (-CHR).
Time from end of strain till the onset of the sustained fall of heart rate (O.F.) and from the onset of fall to control.
Time in whole beats.
Control subjects and patients arranged according to age.

CONTROLS

Athletes

Group/No.	Age	Time to 40 mmHg.	E.S. to O.F.	O.F. to CHR.	E.S. to CHR,	E.S. to -CHR.
1-1	16	.245 secs.	5	2	7	8
1-2	16	.35	5	2	7	7
1-3	16	.56	3	2	5	5
1-4	20	.955	5	3	8	9
1-5	20	1.47	4	2	6	6
1-6	21	1.86	4	2	6	8

Normals

1-7	15½	.53	3	2	5	5
1-8	16	1.15	2	2	4	4
1-9	16	1.22	3	3	6	6
1-10	16	1.88	5	1	6	6
1-11	16	1.42	5	1	6	6
1-12	16	.77	1	3	4	4
1-13	17	.915	4	3	7	7
1-14	17	.96	3	3	6	6
1-15	17	1.1	4	3	7	7
1-16	17	1.723	2	4	6	6
1-17	18	1.56	4	2	6	8
1-18	18	.42	1	2	3	3
1-19	20	.825	6	4	10	11
1-20	20	1.55	1	4	5	5
1-21	22	.89	5	2	7	7

TABLE 16b

Normals

Group/No.	Age	Time to 40 mmHg.	E.S. to O.F.	O.F. to CHR.	E.S. to CHR.	E.S. to -CHR.
1-22	22	2.623	4	3	7	7
1-23	25	1.87	4	2	6	6
1-24	25	1.062	6	1	7	9
1-25	25	.36	3	2	5	5
2-1	26	1.92	1	4	5	5
2-3	32	.96	3	5	8	8
2-4	33	1.055	4	2	6	6
2-5	34	2.362	4	6	10	10
2-6	35	.41	2	3	5	5
2-7	36	1.57	5	3	8	9
3-1	37	.54	4	3	7	7
3-2	37	.4	4	4	8	8
3-3	38	.68	1	3	4	4
3-4	40	1.7	3	4	7	8
3-5	41	1.59	6	7	13	13
3-6	42	1.13	4	2	6	6
3-7	43	1.602	6	3	9	9
3-8	44	1.04	5	4	9	9
3-9	46	1.853	5	3	8	8
4-1	47	.442	6	3	9	9
4-2	47	.365	5	5	10	10
4-3	47	.375	4	3	7	7
4-4	47	.58	4	4	8	8
4-5	47	1.79	5	3	8	8
4-6	49	.42	3	5	8	8
4-7	49	.79	5	2	7	7
4-8	51	1.56	4	5	9	9
4-9	57	2.54	5	5	10	10
4-10	59	2.1	4	4	8	8
4-11	61	1.08	6	4	10	10

TABLE 16b

PATIENTS

Infarction

Group/No.	Age	Time to 40 mmHg.	E.S. to O.F.	O.F. to CHR.	E.S. to CHR.	E.S. to -CHR
5-1	37	3.2	4	6	10	10
5-2	42	-	4	5	9	9
5-3	43	1.22	3	8	11	12
5-4	44	1.16	3	4	7	7
5-5	44	1.79	5	7	12	12
5-6	46	1.475	3	5	8	8
5-7	46	.81	2	6	8	8
5-10	48	2.01	4	8	12	15
5-12	49	1.2	5	4	9	9
5-14	50	2.75	4	7	11	12
5-15	52	2.34	9	3	12	12
5-16	52	.38	2	8	10	10
5-17	53	1.92	3	7	10	10
5-18	54	1.12	2	8	10	12
*5-19	54	2.3	6	5+	11+	12+
5-20	54	.7	6	8	14	14
5-23	55	.93	5	3	8	8
5-21	55	1.69	3	7	10	10
5-22	55	.9	4	5	9	9
5-24	56	-	6	8	14	15
5-25	56	.96	3	6++		
5-26	57	1.58	8	7	15	15
5-27	59	-	4	6	10	15
5-28	60	.7	7	6	13	13
5-29	61	1.19	8	8	16	16

* = H.R. returned to within one beat of average control heart rate.

++ = H.R. returned to within 3 beats of average control heart rate.

TABLE 16c

Heart Rate Response Alone.

Mean Values

Category	Age Yrs	No. of Cases	B.P. mmHg.	CHR. bt/min.	CHR. Range	H.R. Increment Range bt/min.	H.R. Increment Mean bt/min.
Control	16-25	25	126/76	81	51-133	21-64	39
	26-36	7	134/84	79	64-92	13-52	29
	37-46	9	135/84	90	71-105	14-40	29
	47-61	11	137/85	81	57-101	17-47	32
Infarction/ Ischaemia	37-61	24	142/89	75	57-109	8-56	30

Category	E.S. to O.F. Av. Beats	E.S. to O.F. Range Beats	O.F. to CHR. Av. Beats	O.F. to CHR. Range Beats	E.S. to CHR. Av. Beats	E.S. to CHR. Range Beats	Bradycardia Beats below Control Range	Bradycardia Beats below Control Mean
Control								
16-25	3.5	1-6	2.3	1-4	5.8	3-10	5-67	27
26-36	3.1	1-5	4.0	2-6	7.1	5-10	7-28	18
37-46	4.2	1-6	3.6	2-7	7.9	4-13	9-62	27
47-61	4.6	3-6	3.9	2-5	8.0	7-10	6-51	23
Infarction/ Ischaemia	4.6	2-9	5.9	3-8	10.2	7-16	0-41	11

REFERENCES

Agress C.M. and Fields L.G., (1959). Symposium on Phonocardiography, (II). New Method for Analysing Heart Vibrations, (I). Low Frequency Vibrations. Amer. J. Cardiol. 4:184.

Agress C.M. and Fields L.G., (1961). The Analysis and Interpretation of the Vibrations of the Heart, as a Diagnostic Tool and Physiological Monitor. Ire Transactions on Bio-Medical Electronics. 8:178.

Agress C.M., Wegner S., Bleifer D.J., Estrin H.M., Schroyer K., and Labins G., (1964a). Measurement of Isometric Contraction and Ejection Time by the Vibrocardiogram. Amer. J. Cardiol. 13:340.

Agress C.M., Wegner S., Bleifer D.J., Lindsay A., Van Houten J., Schroyer K. and Estrin H.M., (1964b). The Common Origin of Precordial Vibrations. Amer. J. Cardiol. 13:226.

Agress C.M. and Nakakura S., (1964). Variations of the Vibrocardiogram Over the Praecordium. Aerospace Med. 35:752.

Ambrosi C. and Starr I., (1965). Inco-ordination of the Cardiac Contraction, as Judged by the Force Ballistocardiogram and the Carotid Pulse Derivative. Amer. H.J. 70:761.

Amidi M., Leon D.F. and De Groot W.J., (1968). Effect of the Thyroid State on Myocardial Contractility and Ventricular Ejection Rate in Man. Circulation. 38:229.

Anderson K., (1969). Physical Fitness and Cardiovascular Performance of Healthy Subjects in Relation to Physical Training. Mal. Cardiovasc. 10:385.

Aygen M.M. and Braunwald E., (1962). The Splitting of the Second Heart Sound in Normal Subjects and in Patients with Congenital Heart Disease. Circulation. 25:328.

Barner H.B., Kaiser G.C., Willman V.L. and Hanlon C.R., (1968). Pulsus Bisferiens. Circulation. 37-38. Supple. 6-37.

Beilin L. and Mounsey F., (1962). The Left Ventricular Impulse in Hypertensive Heart Disease. Brit. H.J. 24:409.

Benchimol A., Dimond E.G. and Shen Y., (1960). Ejection Time in Aortic Stenosis and Mitral Stenosis. Comparison Between the Direct and Indirect Arterial Tracings, with Special Reference to Pre- and Postoperative Findings. Amer. J. Cardiol. 6:728.

Benchimol A. and Dimond E., (1963). The Normal and Abnormal Apexcardiogram : Its Physiologic Variation and its Relation to Intracardiac Events. Amer. J. Cardiol. 12:368

Benchimol A., Legler J.F. and Dimond E.G., (1963). The Carotid Tracing and Apexcardiogram in Subaortic Stenosis and Idiopathic Myocardial Hypertrophy. Amer. J. Cardiol. 11:427.

Benchimol A. and Ellis J.G. (1967). A Study of the Period of Isovolumic Relaxation in Normal Subjects and in Patients with Heart Disease. Amer. J. Cardiol. 19:196.

Benestad A.M., (1965). Trainability of Old Men. Acta. Med. Scand. 178:321.

Benestad A.M., (1968). Determination of Physical Work Capacity and Exercise Tolerance in Cardiac Patients. Acta. Med. Scand. 183:521.

Berne R.M. and Levy M.N., (1967). Cardiovascular Physiology. The C.V. Mosby Co. Saint Louis.

Berry J.N., (1965). A New Method for Recording Cardiac, Hepatic and Other Pulsations, Movements and Thrills. Amer. Heart J. 71:17.

Bing R.J., Bottcher D. and Cowan C., (1968). What is Cardiac Failure? Amer. J. Cardiol. Sym. Con. Heart Failure. 22:2.

Bondurant S. and Wallace J.M., (1956). Reaction of an Occluded Artery during Normal and Abnormal Valsalva Responses. Circulation. 14:913

Braunwald E, Sonnenblick E.H., Ross J. Jr., Glick G. and Epstein S.E., (1967). An Analysis of the Cardiac Response to Exercise. Circulation Res. 20. Supple. 1.1.

Braunwald E., Ross J. Jr., and Sonnenblick E.H., (1967). Mechanism of Contraction of the Normal and Failing Heart. New Eng. J. Med. 277:962.

Braunwald E., Ross J. Jr. and Gault J.H., (1969). Assessment of Cardiac Function. Ann. Inter. Med. 70:369.

Braveny P. and Sumbera J., (1970). Electromechanical Correlation in the Mammalian Heart Muscle. Pfugers Archiv. 319:36.

Bristow J.D., Honour A.J., Pickering G.W., Sleight P. and Smyth H.S., (1969). Diminished Baroreflex Sensitivity in High Blood Pressure. Circulation. 39:48.

Bristow J.D., Van Zee B.E. and Judkins M.P., (1970). Systolic and Diastolic Abnormalities of the Left Ventricle in Coronary Artery Disease. Studies in Patients with little or no Enlargement of Ventricular Volume. Circulation. 42:219.

Brodie R.E. and Dow R.S., (1968). Studies in Carotid Compression and Carotid Sinus Sensitivity. Neurology. 18:1047.

Burch G.E., Ray C.T. and Cronwich J.A., (1952). Certain Mechanical Peculiarities of the Human Cardiac Pump in Normal and Diseased States. Circulation. 5:504.

Burch G.E., (1955a). The Dilated Heart. Arch. Int. Med. 96:571.

Burch G.E., (1955b). Theoretic Considerations of the Time Course of Pressure Developed and Volume Ejected by the Normal and Dilated Left Ventricle during Systole. Amer. H.J. 50:352.

Burroughs R.W. and Bruce R.A., (1956). Significance of Abnormal Phase II Response to Valsalva Maneuver in Cardiac Patients. Circulation. 14:72.

Carter S.A., (1968). Indirect Systolic Pressures and Pulse Waves in Arterial Occlusive Disease of the Lower Extremities. Circulation. 37:624.

Chadduck W.M. and Ames B.A., (1969). Ptosis and Proptosis following Valsalva Maneuver. Aerospace Med. 40:670.

Chlebus H., (1962). Value of Examination of Carotid Pulse by Means of Resonance Electrosphygmographs in Relation to Intra-Arterial Pressure Tracings. Amer. H.J. 64:22.

Cohen H., (1966). Aortic Flow and Other Hemodynamic Responses to the Valsalva Maneuver in the Dog. Amer. Heart J. 72:784.

Committee on Exercise and Physical Fitness : Is Your Patient Fit? (1967). JAMA. 201:131.

Cooper D., Skillman J.J. and Ciampa G.R., (1967). External Pulse Recording in Experimental Haemorrhage and Drug Infusion in Man. Surg. Gyn. Obst. 125:1246.

Cosby R.S., Herman L., Freibrun L. and Mayo M., (1958). Abnormal Behaviour of Pulmonary and Brachial Artery Pressures during the Valsalva Maneuver in Patients with Emphysema. Circulation. 18:708.

Coulshed N. and Epstein E.J., (1963). The Apexcardiogram : Its Normal Features Explained by These Found in Heart Disease. Brit. H.J. 25:697.

Cudkowicz L., (1968). Normal, Pharmacological and Disordered Systemic Circulatory Response to the Valsalva Manoeuvre. Respiration. 25:81.

Daggett W.M. and Weisfeldt M.L., (1965). Influence of the Sympathetic Nervous System on the Response of the Normal Heart to Digitalis. Amer. J. Cardiol. 16:394.

Daoud G., Reppert E.H. Jr. and Butterworth J.S. (1959). Basal Systolic Murmurs and the Carotid Pulse Curve in the Diagnosis of Calcareous Aortic Stenosis. Ann. Inter. Med. 50:323

Dawson P.M. and Hodges P.C., (1920). Cardio-Vascular Reaction in the Valsalva Experiment and in Lifting with a Note on Parturition. Amer. J. Physiol. 50:481.

Deliyannis A.A., Gillam P.M.S., Mounsey J.P.D. and Steiner R.E. (1964). The Cardiac Impulse and the Motion of the Heart. Brit. Heart J. 26:396.

Derbes V.J. and Kerr A. Jr., (1955). Valsalva's Maneuver and Weber's Experiment. New Eng. J. Med. 253:822.

Diamant B. and Killip T., (1970). Indirect Assessment of Left Ventricular Performance in Acute Myocardial Infarction. Circulation. 42:579.

Dodge H.T. and Baxley W.A., (1968). Hemodynamic Aspects of Heart Failure. Amer. J. Cardiol. 22:24.

Dontas A.S., (1960). Comparison of Simultaneously Recorded Intra-Arterial and Extra-Arterial Pressure Pulses in Man. Amer. Heart J. 59:576.

Dontas A.S. and Simonson E., (1961). Carotid Pulses and Peripheral Plethysmograms at Rest. Comparison between Older Healthy Men and Men with Coronary Artery Disease. Circulation Res. 9:450.

Dontas A.S., Keys A. and Anthopoulos L., (1970). Effects of Age on the Carotid Pulse in Two Greek Populations. Circulation. 42:529.

Downing S.E. and Gardner T.H., (1968). Cephalic and Carotid Reflex Influences on Cardiac Function. Amer. J. Physiol. 215:1192.

Doyle A.E. and Neilson G.H., (1957). The Valsalva Manoeuvre in Aortic Valve Disease. Brit. Heart J. 19:525.

Duchosal P.W., Ferrero C., Leupin A. and Urdanetta E., (1956). Advance in the Clinical Evaluation of Aortic Stenosis by Arterial Pulse Recordings of the Neck. Amer. Heart J. 51:861.

Edwards E.A. and Ottinger L., (1958). Pulse Registration in the Study of Peripheral Arterial Disease. New Eng. J. Med. 259:101.

Elisberg E.I., Goldberg H. and Snider G.L., (1951). Value of Intraoral Pressure as a Measure of Intrapleural Pressure. J. Applied Physiol. 4:171.

Elisberg E.I., Singian E. and Miller G., (1952). Influence of Heart Disease on Expected Overshoot in Blood Pressure following a Valsalva Maneuver. Fed. Amer. Soc. for Exp. Biology. 11:42.

Elisberg E.I., Singian E., Miller G. and Katz L.N., (1953). The Effect of the Valsalva Maneuver on the Circulation; The Influence of Heart Disease on the Expected Post-Straining Overshoot. Circulation. 7:880.

Elisberg E.I., (1963). Heart Rate Response to the Valsalva Maneuver as a Test of Circulatory Integrity. JAMA. 186:200.

Elison R.C. and Levin A.B., (1968). Estimation of Shunt Flows in Septal Defects with the Valsalva Maneuver. Circulation. 37-38. Supple. 6-71.

Flack M., (1919). Some Simple Tests of Physical Efficiency. Lancet. 1:210.

Flack M., (1921). Respiratory Efficiency in Relation to Health and Disease. Lancet. 2:637.

Flessas A.P., Kumar S. and Spodick D.H., (1970). Effects of the Valsalva Maneuver on the Cardiac Systolic Intervals; Beat-to-Beat Versus Times Analysis. Amer. Heart J. 80:522.

Fox I.J., Crowley W.P. Jr., Grace J.B. and Wood E.H., (1966). Effects of the Valsalva Maneuver on Blood Flow in the Thoracic Aorta in Man. J. Appl. Physiol. 21:1553.

Frank M.N. and Kinlaw W.B., (1962). Indirect Measurement of Isovolumetric Contraction Time and Tension Period in Normal Subjects. Amer. J. Cardiol. 10:800.

Frick M.H. and Katila M., (1968). Hemodynamic Consequences of Physical Training after Myocardial Infarction. Circulation. 37:192.

Freis E.D., Heath W.C., Luchsinger P.C., Snell R.E., (1966). Changes in the Carotid Pulse which Occur with Age and Hypertension. Amer. Heart J. 71:757.

Garrard C.L. Jr., Weissler A.M. and Dodge H.T., (1970). The Relationship of Alterations in Systolic Time Intervals to Ejection Fraction in Patients with Cardiac Disease. Circulation. 42:455.

Gebber G.L., Snyder D.W., (1970). Hypothalamic Control of Baroreceptor Reflexes. Amer. J. Physiol. 218:124.

Goldberg H., Elisberg E.I. and Katz, (1952). The Effects of the Valsalva-Like Maneuver upon the Circulation in Normal Individuals and Patients with Mitral Stenosis. Circulation. 5:38.

Goldblatt A., Harrison D.C. and Glick G., (1963). Studies on Cardiac Dimensions in Intact, Unanesthetized Man. II. Effects of Respiration. Circulation Res. 13:448.

Gorlin R., Knowles J.H. and Storey C.F., (1957). The Valsalva Maneuver as a Test of Cardiac Function. Amer. J. Med. 22:197.

Gorlin R., Brachfield N., MacLeod C. and Bopp P., (1959). Effect of Nitroglycerine on the Coronary Circulation in Patients with Coronary Artery Disease or Increased Left Ventricular Work. Circulation. 29:705.

Gorlin R., (1962). The Hyperkinetic Heart Syndrome. JAMA. 182:823.

Gorlin R. and Sonnenblick E.H., (1968). Regulation of Performance of the Heart. Amer. J. Cardiol. Sym. Cardiac Failure. 22:16.

Gould A. and Shariff M., (1969). Comparison of the Left Ventricular Aortic and Brachial Arterial First Derivative. Vasc. Surg. 3:34.

Granath A., Jonsson B. and Strandell T., (1964). Circulation in Healthy Old Men, Studied by Right Heart Catheterisation at Rest and during Exercise in Supine and Sitting Position. Acta. Med. Scand. 176:425.

Graves C.L., Stauffer W.M., Klein R.L. and Underwood P.S., (1968). Aortic Pulse Contour Calculation of Cardiac Output. Anesthesiology. 29:580.

Greene D.G. and Bunnell I.L., (1953). The Circulatory Response to the Valsalva Maneuver of Patients with Mitral Stenosis With and Without Autonomic Blockade. Circulation. 8:264.

Greenfield J.C. Jr., Tindall G.T., Dillon M.I. and Mahaley M.S., (1964). Mechanics of the Human Carotid Artery in Vivo. Circulation Res. 15:240.

Greenfield J.C. Jr., Cox R.L., Hermandez R.R., Thomas C. and Schoonmaker F.W., (1967). Pressure-Flow Studies in Man during the Valsalva Maneuver with Observations on the Mechanical Properties of the Ascending Aorta. Circulation. 35:653.

Greenfield J.C. Jr., Harley A., Thompson H.K. and Wallace A.G., (1968). Pressure-Flow Studies in Man during Atrial Fibrillation. J. Clin. Invest. 47:2411.

Guyton A.C., (1967). Textbook of Medical Physiology. W.B. Saunders Co., Philadelphia.

Guyton A.C., Coleman T.G., Fourcade J.C. and Navar L.G., (1969). Physiologic Control of Arterial Pressure. N.Y. Acad. Med. 45:811.

Hainsworth R. and Karim F., (1969). Aortic Baroreceptors and the Heart. J. Physiol. (London). 204:16P.

Hamer J., (1968). Hemodynamics of Hypertension. Amer. Heart J. 76:149.

Hamley E.J. and Thomas V., (1969). Comparison of Rowing and Cycling Work Capacity Tests Using Heart Rate as the Parameter. J. Physiol. (London). 203:80P.

Hamilton W.F., Woodbury R.A. and Harper H.T. Jr., (1936). Physiologic Relationships between Intrathoracic, Intraspinal and Arterial Pressures. JAMA. 107:853.

Hamilton W.F., Woodbury R.A. and Harper H.T. Jr., (1944). Arterial, Cerebrospinal and Venous Pressures in Man during Cough and Strain. Amer. J. Physiol. 141:42.

Hanson J.S., Tabakin B.S. and Levy A.M., (1966). Comparison of Cardiorespiratory Responses to Graded Upright Exercises of Normal Men aged 20-29 and 30-39. Brit. Heart J. 28:557.

Hanson J.S., Tabakin B.S. and Levy A.M., (1968). Comparative Exercise Cardiorespiratory Performance of Normal Men in the Third, Fourth and Fifth Decades of Life. Circulation. 37:345.

Harley A., Starmer C.F. and Greenfield J.C. Jr., (1969). Pressure-Flow Studies in Man. An Evaluation of the Duration of the Phases of Systole. J. Clin. Invest. 48:895.

Harris L.C., Weissler A.M., Manske A.O., Danford B.H., White G.D. and Hamilton W.A., (1964). Duration of the Phases of Mechanical Systole in Infants and Children. Amer. J. Cardiol. 14:448.

Harrison T.R., Dixon K., Russell R.O. Jr., Bidwai P.S. and Coleman H.N., (1964). The Relation of Age to the Duration of Contraction, Ejection and Relaxation of the Normal Human Heart. Amer. Heart J. 67:189.

Herd J.A., Leclair N.R., and Simon W., (1966). Arterial Pressure Pulse Contours during Hemorrhage in Anesthetized Dogs. J. Appl. Physiol. 21:1864.

Hermann H.J., Singh R. and Dammann J.F., (1969). Evaluation of Myocardial Contractility in Man. Amer. Heart J. 77:755.

Hood W.B. Jr., McCarthy B. and Lown B., (1969). Aortic Pressure Loading in Dogs with Myocardial Infarction. Amer. H.J. 77:55.

Howard P., (1965). Indirect Methods for Measurement of Blood Pressure. Proc. Roy. Soc. Med. 58:781.

Inoue K., Young G.M., Grierson A.L., Smulyan H. and Eich R.H., (1970). Isometric Contraction Period of the Left Ventricle in Acute Myocardial Infarction. Circulation. 42:79.

Jones W.B., Hefner L.L., Bancroft W.H. Jr., and Klip W., (1959). Velocity of Blood Flow and Stroke Volume obtained from the Pressure Pulse. J. Clin. Invest. 38:2087.

Jones W.B. and Reeves T.J., (1968). Total Cardiac Output Response during Four Minutes of Exercise. Amer. Heart J. 76:209.

Judson W.E., Hatcher J.D. and Wilkins R.W., (1955). Blood Pressure Responses to the Valsalva Maneuver in Cardiac Patients with and without Congestive Failure. Circulation. 11:889.

Julius S. and Conway J., (1968). Hemodynamic Studies in Patients with Borderline Blood Pressure Elevation. Circulation. 38:282.

Kay C.F., Woods J.W., Zinsser H.F. and Benjamin J.A.M., (1949). The Validity of the Electrokymographic Method for Measurement of the Diameter Change of the Aorta and Pulmonary Artery during Circulatory Disturbance. J. Clin. Invest. 28:228.

Kellermann J.J., Levy M., Feldman S. and Hariv I., (1967). Rehabilitation of Coronary Patients. J. Chronic. Dis. 20:815.

Kemmerer W.T., Stegall H.F. and Evans W.E., (1967). Indirect Measurement of Human Blood Pressure by the Doppler Ultrasonic Technique. Amer. Coll. Surgeons. Surg. Forum. 8:163.

Kettner M.G., Ferrero C., and Duchosal P.W., (1955). Clinical Investigation by the Oscillogram of Peripheral Arteries. Amer. Heart J. 49:485.

Klein I.J., Saltxman H.A., Heyman A., (1964). Syncope Induced by the Valsalva Maneuver. A Study of the Effects of Arterial Blood Gas Tensions. Glucose Concentration and Blood Pressure. Amer. J. Med. 37:263.

Kouchoukos N.T., Sheppard L.C., McDonald D.A. and Kirklin J.W., (1968). Estimation of Stroke Volume and Cardiac Output from the Central Arterial Pulse Contour in Postoperative Patients. Circulation. 37-38. Supple. 6-118.

Koushanpour E. and McGhee J.P., (1969). Effect of Mean Pressure on Carotid Sinus Baroreceptor Response to Pulsatile Pressure. Amer. J. Physiol. 216:599.

Krasnow N., Rolett E., Hood W.B., Yurchak P.M. and Gorlin R., (1963). Reversible Obstruction of the Ventricular Outflow Tract. Amer. J. Cardiol. 11:1.

Kroeker E.J. and Wood E.H., (1956). Beat-to-Beat Alterations in Relationship of Simultaneously Recorded Central and Peripheral Arterial Pressure Pulses during Valsalva Maneuver and Prolonged Expiration in Man. J. Appl. Physiol. 8:483.

Lalossis D.A., Dontas A.S., Balas P.B. and Christeas N., (1966). Arterial Pulse Vibrations in Aging and Arterial Disease. J. Gerantol. 21:230.

Lategola M.T., Harrison H., and Barnard C., (1966). A Virtually Continuous Measurement of Human Systolic and Diastolic Blood Pressure Transients without Direct Arterial Puncture. Aerospace Med. 37:228.

Lategola M.T. and Naughton J., (1967). Restoration of Cardiovascular Integrity in Post Myocardially-Infarcted Aviation Personnel. Aerospace Med. 38:1067.

Lee G. de J., Matthews M.B. and Sharpey-Schafer E.P., (1954). The Effect of the Valsalva Manoeuvre on the Systemic and Pulmonary Arterial Pressure in Man. Brit. H.J. 16:311.

Levine H.J., McIntyre K.M. and Glovsky M.M., (1966). Relief of Angina Pectoris by Valsalva Maneuver. New Eng. J. Med. 275:487.

Lohr H.A., Van Vollenhoven E. and Van Rotterdam A., (1963). Fundamentals in Vibrocardiography. Precordial Accelerography and Acceleration Ballistocardiography. Amer. Heart J. 66:108.

London R.E. and London S.B., (1966). Blood Pressure Survey of Physicians. Use of Automated Measurements. JAMA. 198:117.

Lorentsen E., Bay G., Grendahl H., and Silvertssen E., (1967). The Hemodynamic Effect of Changes in Posture in Cardiac Patients. Acta. Med. Scand. 182:175.

McDonald D.A., (1960). Blood Flow in Arteries. Monographs of the Physiological Society No. 7.

McIntosh H.D., Burnum J.F., Hickman J.B. and Warren J.V., (1954). Circulatory Changes Produced by the Valsalva Maneuver in Normal Subjects, Patients with Mitral Stenosis and Autonomic Nervous System Alterations. Circulation. 9:511.

Marcus F.I., Westura E.E., and Summa J., (1964). The Hemodynamic Effect of the Valsalva Maneuver in Muscular Stenosis. Amer. Heart J. 67:324.

Marx H.J. and Yu P.N., (1967). Clinical Examination of the Arterial Pulse. Progr. Cardiovasc. Dis. 10:207.

Mason D.T. and Braunwald E., (1963). Studies on Digitalis IX. Effects of Oubain on the Nonfailing Human Heart. J. Clin. Invest. 42:1105.

Mason D.T., Braunwald E., Ross J. Jr. and Morrow A.G., (1964). Diagnostic Value of the First and Second Derivatives of the Arterial Pressure Pulse in Aortic Valve Disease and in Hypertrophic Subaortic Stenosis. Circulation. 30:90.

Mason D.T., (1969). Usefulness and Limitations of the Rate of Rise of Intraventricular Pressure (dp/dt) in the Evaluation of Myocardial Contractility in Man. Amer. J. Cardiol. 23:516.

Messer J.V., Levine H.J., Wagman R.J. and Gorlin R., (1963). Effect of Exercise on Cardiac Performance in Human Subjects with Coronary Artery Disease. Circulation. 28:404.

Metzger C.C., Chough C.B. and Kroetz F.W., (1970). True Isovolumic Contraction Time. Its Correlation with Two External Indexes of Ventricular Performance. Amer. J. Cardiol. 25:434.

Mills J.N., (1950). Pressures Developed in Abdomen and Thorax during Flack Tests. J. Physiol. 111:368.

Mills H. and Kattus A., (1958). The Emphysema Response to Forced Straining. (Valsalva's Maneuver). Circulation. 17:65.

Mitchell J.H., Wallace A.G. and Skinner N.S. Jr., (1963). Intrinsic Effects of Heart Rate on Left Ventricular Performance. Amer. J. Physiol. 205:41.

Mitchell J.H., Wallace A.G. and Skinner N.S. Jr., (1966). Relation between End-Diastolic Pressure and Mean Rate of Ejection of Left Ventricle. Amer. J. Physiol. 211:83.

Murphy G.W., Schreiner B.F., Bleakley P.L. and Yu P.N. (1964). Left Ventricular Performance following Digitilisation in Patients with and without Heart Failure. Circulation. 30:358.

Nager F., Thomas M. and Shillingford J., (1967). Changes in Cardiac Output and Stroke Volume during First Four Months after Cardiac Infarction. Brit. H.J. 29:859.

Nakakura S., Agress C.M. and Wegner S., (1965). Influence of Heart Rate on the Phases of the Left Heart Cycle in Exercise. Jap. Heart J. 6:104.

Nimura Y., Matsua H. and Mochizuki S., (1968). Analysis of a Cardiac Cycle of the Left Side of the Heart in Cases of Left Ventricular Overloading or Damage with the Ultrasonic Doppler Method. Amer. Heart J. 75:49.

Noble M.I., (1968). The Contribution of Blood Momentum to Left Ventricular Ejection in the Dog. Circ. Res. 23:663.

Nutter D.O. and Hurst V.W., (1968). The Maximum Acceleration of Aortic Blood Flow. An Index of Ventricular Performance. Circulation. 37-38. Supple. 6-149.

Papaevangelou E., Moran J.M. and Callow A.D., (1968). Hemodynamic Effects of Pulseless Renal Blood Flow. Circulation. 37-38. Supple. 6-153.

Pool P.E. and Braunwald E., (1968). Fundamental Mechanism in Congestive Heart Failure. Amer. J. Cardiol. 22:7.

Pouget J.M., Harris W.S., Mayron B.R. and Naughton J.P., (1971). Abnormal Responses of the Systolic Time Intervals to Exercise in Patients with Angina Pectoris. Circulation. 43:289.

Price H.L. and Connor E.H., (1953). Certain Aspects of the Hemodynamic Response to the Valsalva Maneuver. J. Appl. Physiol. 5:449.

Reeves T.J., Hefner L.L., Jones W.B. and Sparks J.E., (1957). Wide Frequency Range Force Ballistocardiogram; Its Correlation with Cardiovascular Dynamics. Circulation. 16:43.

Rios J.C. and Massumi R.A., (1965). Correlation between the Apexcardiogram and Left Ventricular Pressure. Amer. J. Cardiol. 15:647.

Robinson B., (1963a). The Carotid Pulse. Diagnosis of Aortic Stenosis by External $R_e$cordings. Brit. Heart J. 25:51.

Robinson B., (1963b). The Carotid Pulse II. Relation of External Recordings to Carotid, Aortic and Brachial Pulses. Brit. Heart J. 25:61.

Ross J. Jr., and Braunwald E., (1964). Studies on Starling's Law of the Heart. IX. The Effects of Impeding Venous Return on Performance of the Normal and Failing Human Left Ventricle. Circulation. 30:719.

Rovetto M.J. and Lefer A.M., (1970). Electrophysiologic Properties of Cardiac Muscle in Adrenal Insufficiency. Amer. J. Physiol. 218:1015.

Ruskin J., Harley A., and Greenfield J.C. Jr., (1968). Pressure Flow Studies in Patients having a Pressor Response to the Valsalva Maneuver. Circulation. 38:277.

Rushmer R.F., (1964). Initial Ventricular Impulse. A Potential Key to Cardiac Evaluation. Circulation. 29:268.

Russell R.O., Porter C. McG., Frimer M., and Dodge H.T., (1971). Left Ventricular Power in Man. Amer. Heart J. 81:799.

Salisbury P.F., Cross C.E. and Rieben P.A., (1962). Ventricular Performance Modified by Elastic Properties of Outflow System. Circ. Res. 11:319.

Sarnoff S.J., Hardenbergh E. and Whittenberger J.L., (1948). Mechanism of the Arterial Pressure Response to the Valsalva Test: The Basis for Its use as an Indicator of the Intactness of the Sympathetic Outflow. Amer. J. Physiol. 154:316.

Scher, A.M. and Young A.C., (1963). Servoanalysis of Carotid Sinus Reflex Effects on Peripheral Resistance. Circ. Res. 12:152.

Scher A.M. and Young A.C., (1969). Nonlinearity in the Control of Blood Pressure and Heart Rate. N.Y. Acad. Sci. Annals. 156:722.

Scott D.B., Slawson K.B. and Taylor S.H., (1969). The Circulatory Effects of the Valsalva Maneuver during Anesthesia and Thoracotomy. Cardiovasc. Res. 3:331.

Sharpey-Schafer E.P., (1955). Effects of Valsalva's Maneuver of the Normal and Failing Circulation. Brit. Med. J. 1:693. March 19th.

Sharpey-Schafer E.P., (1965). Handbook of Physiology. Section 2. Circulation. 3:1875. American Physiological Society. Washington D.C.

Shaver J.A., Kroetz F.W., Leonard J.J. and Paley H.W., (1968). The Effect of Steady State Increases in Systemic Arterial Pressure on the Duration of Left Ventricular Ejection Time. J. Clin. Invest. 47:217.

Skillman J.J., Olson J.E., Lyons J.H. and Moore F.D., (1967). The Hemodynamic Effect of Acute Blood Loss in Normal Man, with Observations on the Effect of the Valsalva Maneuver and Breath Holding. Annals of Surg. 166:713.

Smith J.E. and Kidera G.J., (1967). Treatment of Angina Pectoris with Exercise Stress. Aerospace Med. 38:742.

Sokolow M., Werdegar D. and Kain H.K., (1966). Relationship between Level of Blood Pressure Measured Casually and by Portable Recorders and Severity of Complications in Essential Hypertension. Circulation. 34:279.

Sonnenblick E.H. and Downing S.E., (1963). Afterload as a Primary Determinant of Ventricular Performance. Amer. J. Physiol. 204:604.

Sonnenblick E.H., Ross J. Jr., Covell J.W., Kaiser G.A. and Braunwald E., (1965). Velocity of Contraction as a Determinant of Myocardial Oxygen Consumption. Amer. J. Physiol. 209:919.

Sonnenblick E.H., Morrow A.G. and Williams J.F. Jr., (1966). Effects of Heart Rate on the Dynamics of Force Development in the Intact Human Ventricle. Circulation. 33:945.

Sonnenblick E.H., Williams J.F. Jr., Glick G., Mason D.T. and Braunwald E., (1966). Studies on Digitalis XV. Effects of Cardiac Glycosides on Myocardial Force-Velocity Relations in the Nonfailing Human Heart. Circulation. 34:532.

Spann J.F., Mason D.T. and Zelis R.F., (1969). The Altered Performance of the Hypertrophied and Failing Heart. Amer. J. Med. Sci. 258:291.

Spencer M.P. and Greiss F.C., (1962). Dynamics of Ventricular Ejection. Circ. Res. 10:274.

Spodick D.H. and Kumar S., (1968a). Electromechanical Lag of the Left Ventricle. Cardiovasc. Res. 2:338.

Spodick D.H. and Kumar S., (1968b). Isovolumic Contraction Period of the Left Ventricle. Results in a Normal Series and Comparison of Methods of Calculation by Atraumatic Techniques. Amer. H.J. 76:498.

Spodick D.H. and Kumar S., (1968c). Left Ventricular Ejection Period. Measurement by Atraumatic Techniques: Results in Normal Young Men and Comparison of Methods of Calculation. Amer. H.J. 76:70.

Spodick D.H., Dorr C.A. and Calabrese B.F., (1969). Detection of Cardiac Abnormality by Clinical Measurement of Left Ventricular Ejection Time. JAMA. 209:239.

Stafford R.W., Harris W.S. and Weissler A.M., (1970). Left Ventricular Systolic Time Intervals as Indices of Postural Circulatory Stress in Man. Circulation. 41:485.

Starr I. and Ogawa S., (1963). A Clinical Study of the First Derivative of the Brachial Pulse. Normal Standards and Abnormalities Encountered in Heart Disease. Amer. Heart J. 65:482.

Starr I., (1967). Further Experience with Simultaneous Records of ULF Force and Carotid Pulse Derivative. Bibliotheca Cardiologica. 19:99.

Stucki P., Hatcher J.D., Judson W.E. and Wilkins R.W., (1955). Studies of Circulation Time during Valsalva Test in Normal Subjects and on Patients with Congestive Heart Failure. Circulation. 11:900.

Stone D.J., Lyon A.F. and Teirstein A.S., (1965). A Reappraisal of the Circulatory Effects of the Valsalva Maneuver. Amer. J. Med. 39:923.

Sucec A., (1969). Oxygen Uptake and Heart Rate in Middle-Aged Males in an Adult Fitness Programme. Amer. Corrective Therapy J. 23:98.

Tafur E., Chem L.S. and Levine H.D., (1964). The Apexcardiogram in Left Ventricular Outflow Tract Obstruction. Circulation. 30:392.

Taylor D.E., Wade J.D., Shishodia M.S. and Hider C.F., (1968). Effects of Selective Myocardial Inactivation on Left Ventricular Function during the Isovolumetric Phase of Systole. Quart J. Exp. Physiol. 53:273.

Thomas M. and Shillingford J., (1965). The Circulatory Response to a Standard Postural Change in Ischaemic Heart Disease. Brit. Heart J. 27:17.

Trinkle J.K., Helton N.E., Bryant L.R. and Wood R.C., (1968). Metabolic Comparison of Pulsatile and Mean Flow for Cardiopulmonary Bypass. Circulation. 37-38. Supple. 6-196.

Tuckman J., and Shillingford J., (1966). Effect of Different Degrees of Tilt on Cardiac Output, Heart Rate and Blood Pressure in Normal Man. Brit. Heart J. 28:32.

Turner A.F. and Jacobson G., (1969). The Valsalva Maneuver in the Diagnosis of Left Ventricular Aneurysm. Radiology. 93:9.

Wallace A.G., Mitchell J.H., Skinner N.S. and Sarnoff S.J., (1963). Duration of the Phases of Left Ventricular Systole. Circ. Res. 12:611.

Warner H.R., Swan H.J.C., Connolly D.C., Tompkins R.G. and Wood E.H., (1953). Quantitation of Beat-to-Beat Changes in Stroke Volume from the Aortic Pulse Contour in Man. J. Applied Physiol. 5:495.

Warner H.R., (1966). The Role of Computers in Medical Research. JAMA. 196:944.

Wayne H.H., (1968). Serial Apexcardiograms, Phonocardiograms and Carotid Tracings in Myocardial Infarction. Circulation. 37-38. Supple. 6-203.

Weil M.H., Shubin H. and Rand W., (1966). Experience with a Digital Computer for Study and Improved Management of the Critically Ill. JAMA. 198:1011.

Weissler A.M., Leonard J.J. and Warren J.V., (1958). Observations on the Delayed First Heart Sound in Mitral Stenosis and Hypertension. Circulation. 18:165.

Weissler A.M., Peeler R.G. and Roehill W.H. Jr., (1961). Relationships between Left Ventricular Ejection Time, Stroke Volume, and Heart Rate in Normal Individuals and Patients with Cardiovascular Disease. Amer. Heart J. 62:367.

Weissler A.M., Roehill W.H. Jr. and Peeler R.G., (1962). Effect of Posture on the Cardiac Response to Increased Peripheral Demand. J. Lab. Clin. Med. 59:1000.

Weissler A.M., Harris L.C. and White G.D., (1963). Left Ventricular Ejection Time Index in Man. J. Appl. Physiol. 18:919.

Weissler A.M., Gamel W.G., Grode H.E., Cohen S. and Schoenfeld G.D., (1964). The Effect of Digitalis on Ventricular Ejection in Normal Human Subjects. Circulation. 29:721.

Weissler A.M., Kamen A.R., Bornstein R.S., Schoenfeld C.D. and Cohen S., (1965). The Effect of Deslanoside on the Duration of the Phases of Ventricular Systole in Man. Amer. J. Cardiol. 15:153.

Weissler A.M., Snyder J.R., Schoenfeld C.D., and Cohen S., (1966). Assay of Digitalis Glycosides in Man. Amer. J. Cardiol. 17:768.

Weissler A.M., Harris W.S. and Schoenfeld C.D., (1968). Systolic Time Intervals in Heart Failure in Man. Circulation. 37:149.

Weissler A.M., Harris W.S. and Schoenfeld C.D., (1969). Bedside Technics for the Evaluation of Ventricular Function in Man. Amer. J. Cardiol. 23:577.

Wells B., (1954). The Assessment of Mitral Stenosis by Phonocardiography. Brit. Heart J. 16:261.

Wennevold A., (1967). The Valsalva Maneuver after Operation for Atrial Septal Defect. A Phonocardiographic Assessment of the Operative Result. Acta. Med. Scand. 182:575.

Wiener L., Dwyer E.M., Cox J.W., (1968). Left Ventricular Hemodynamics in Exercise-Induced Angina Pectoris. Circulation. 38:240.

Wiggers C.J., (1921). Studies on the Consecutive Phases of the Cardiac Cycle. 1. The Duration of the Consecutive Phases of the Cardiac Cycle and the Criteria for their Precise Determination. 11. The Laws Governing the Relative Durations of Ventricular Systole and Diastole. Amer. J. Physiol. 56:415.

Wildenthal K., Mierzwiak D.S., and Mitchell J.H., (1969). Effect of Sudden Changes in Aortic Pressure on Left Ventricular dp/dt. Amer. J. Physiol. 216:185.

Wilkins R.W., Culbertson J.W. and Smithwick R.H., (1948). Effects of Various Types of Sympathectomy Upon Vasopressor Responses in Hypertensive Patients. Surg. Gyn. Obst. 87:661.

Willems J.L., Roelandt J., De Geest H., Kesteloot H. and Joosens J.V., (1970). The Left Ventricular Ejection Time in Elderly Subjects. Circulation. 42:37.

Wilson M.F., Clarke N.P., Smith O.A. and Rushmer R.F., (1961). Interrelation between Central and Peripheral Mechanisms Regulating Blood Pressure. Circ. Res. 9:491.